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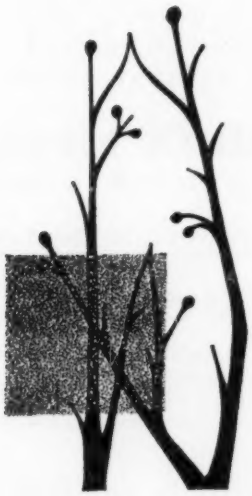

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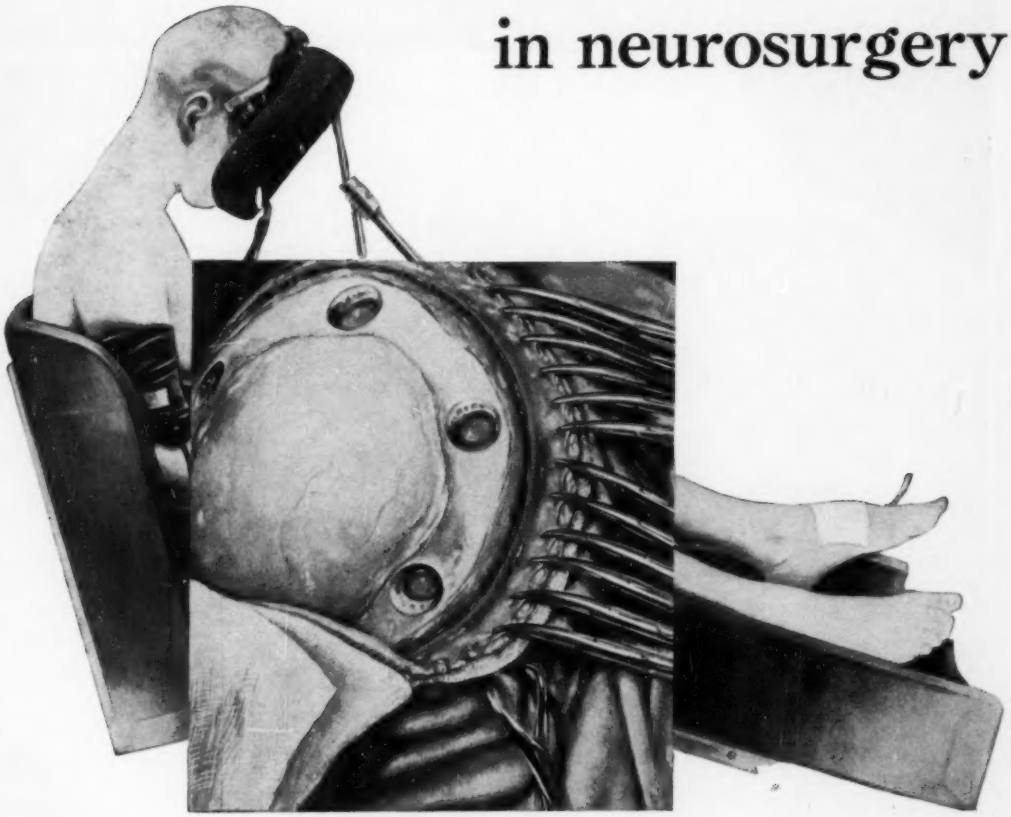

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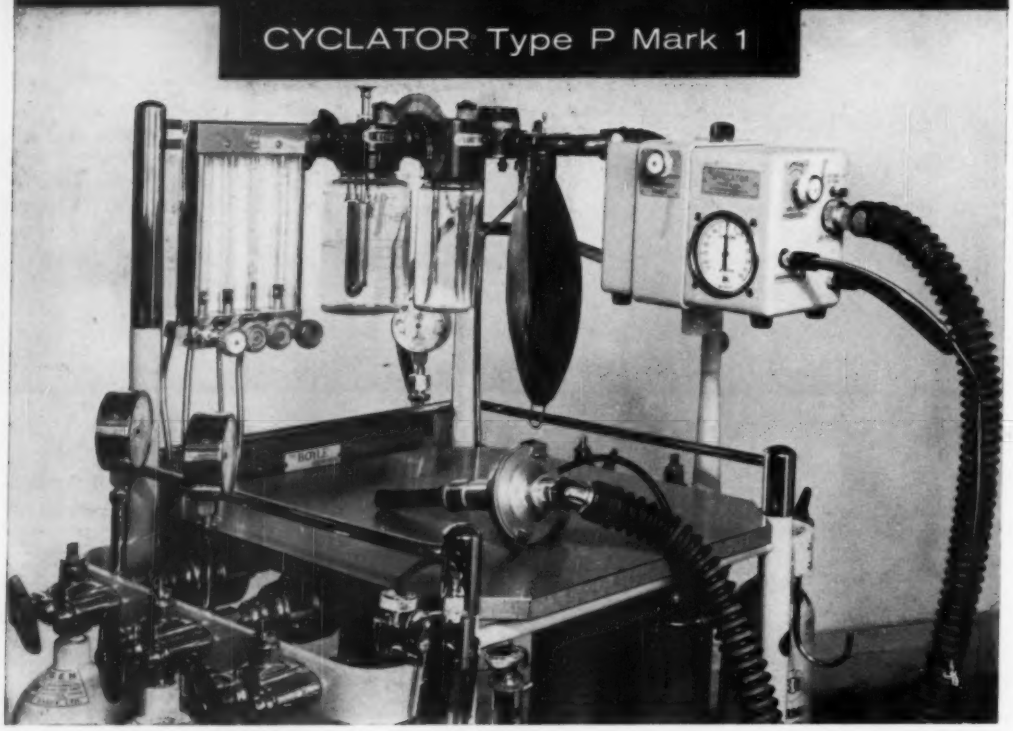

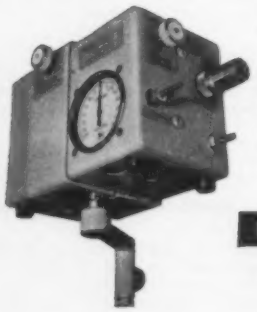

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BRITISH JOURNAL OF ANAESTHESIA

VOL. XXXIII, No. 12 DECEMBER 1961

EDITORIAL

PRE-ANAESTHETIC MEDICATION

The use of morphine in pre-anaesthetic medication has been under criticism for some years. The grounds include inadequate tranquillizing effect, reduced reflex circulatory control, depression of respiration and of the cough reflex and its influence in postoperative vomiting. Further it is difficult to justify the use of an analgesic drug in patients not in pain.

In spite of these arguments it is probably the case that a great many anaesthetists continue to use morphine alone as the sedative component. Many others use it in combination with drugs such as promethazine. The use of pethidine as an alternative is probably open to much the same objections.

Much effort has been expended with the objective of replacing morphine but there is not, as yet, a widely accepted substitute which is substantially free from its disadvantages and which is, at the same time, without additional side effects, such as postoperative restlessness and delay in awakening.

The careful work on analgesimetry, and on the induction side effects of rapidly acting barbiturates, carried out by the members of the Belfast school during the past two years provides some evidence in favour of the retention of an analgesic drug in premedication. These workers have observed a relationship between the incidence of excitatory phenomena following methohexitone induction of anaesthesia and the analgesic action of the premedication.

The same findings applied, but to a lesser extent, when thiopentone was used. Promethazine alone, for example, was associated with a higher incidence of excitatory complications than when it was combined with pethidine. These findings may well prove to be of fundamental importance in any search for new premedicant combinations.

In our last issue we published the eighth paper in the analgesimetry series by Drs. Dundee, Nicholl and Moore, in which studies of atropine and hyoscine were reported. The prolonged antanalgesic action of hyoscine demonstrated here can be correlated with their earlier observations. Using atropine for comparison it was found that hyoscine was associated with an increased incidence of induction complications with methohexitone—a tendency which was less evident when pethidine was combined with hyoscine.

It is of interest also that Eckenhoff, Kneale and Dripps (1961), in a clinical survey of postoperative excitement, noted that, among many other factors, hyoscine was associated with a higher incidence of postoperative agitation than was atropine and that the addition of an opiate to premedication reduced the incidence of postoperative excitement.

Perhaps there are still good reasons for the more conservative, and for those who feel strongly about the desirability of early postoperative awakening, to retain the traditional morphine and atropine premedication, despite its drawbacks, until further investigation provides good evidence for a change of prescription.

REFERENCE

Eckenhoff, J. E., Kneale, D. H., and Dripps, R. D. (1961). The incidence and etiology of postanesthetic excitement: a clinical survey. *Anesthesiology*, **22**, 667.

Brit. J. Anaesth. (1961), 33, 600

VASCULAR DISTENSIBILITY OF THE HAND DURING PRESSURE BREATHING

BY

W. E. WATSON

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THE distensibility of a system is the change in volume which results from unit change in distending pressure when sufficient time is allowed for the system to become stable. The vascular distensibility of the hand is therefore the change in hand blood volume which results from unit change in the pressure distending the vessels of the hand.

METHODS

In this investigation the vessels of the hand were intermittently distended by inflating a pneumatic cuff around the wrist so that venous return from the hand was obstructed. The rate of increase of hand volume was initially equal to the hand blood flow but decreased as the venous pressure approached the pressure within the pneumatic cuff as some blood then leaked proximally.

Hand blood volume changes were measured as hand volume changes with a water-filled, stirred plethysmograph of 5.16 litres capacity maintained at a temperature of $34 \pm 0.5^{\circ}C$. The water within the plethysmograph exerted a hydrostatic pressure of 8 to 11 cm H_2O upon the back of the hand, which was at the level of the subject's manubrium sterni. Hand volume changes were derived from pressure changes in the air contained in the turret of the plethysmograph. Ambient temperature was within the range 22 to 25°C and constant throughout each investigation.

Hand venous pressure was measured through a nylon catheter of 0.8 mm internal diameter introduced percutaneously on the dorsal or radial aspect of the radiocarpal joint and directed peripherally, negotiating at least one venous valve until the end of the catheter lay about 5 cm distal to the site at which the vein was punctured. Care was taken that the end of the catheter was not wedged within a venous tributary or within the sinus of a venous valve. The catheter was periodically flushed with 0.2 ml of saline containing 0.01 mg/ml of heparin.

The vascular distending pressure, or *transmural venous pressure* of the hand is the difference between the pressure within the vein and the pressure within the loose extravenous connective tissue of the back of the hand.

Between episodes of venous obstruction:

$$P_D = P_V - P_T$$

where P_D = vascular distending pressure;
P_V = measured venous pressure;
P_T = pressure in the extravenous connective tissue.

The pressure within the loose connective tissue and within the hand vein was always equal to the hydrostatic pressure of 8 to 11 cm H_2O imposed by the column of water within the plethysmograph above the back of the hand (Watson, unpublished data). This indicates that the imposed hydrostatic pressure was transmitted directly both to the connective tissue and to the veins of the hand. Between episodes of hand venous tamponade the vascular distending pressure was therefore zero, or near zero, indicating that the veins were collapsed (Ryder, Molle and Ferris, 1944).

During episodes of venous obstruction the hand volume increased and the pressure within the plethysmograph rose. This increase in pressure within the plethysmograph was transmitted directly to the loose extravenous connective tissues of the back of the hand (Watson, unpublished data). The increase in venous distending pressure at a given instant during an episode of venous obstruction was therefore derived from the measured increase in venous pressure by sub-

This investigation was supported by a grant from the National Fund for Research into Poliomyelitis.

tracting the measured increase in pressure within the plethysmograph.

$$P_D = P_V - P_T$$

where P_D = increase in vascular distending pressure at a given instant during venous obstruction;

P_V = measured increase in venous pressure at a given instant during venous obstruction;

P_T = simultaneous measured increase in pressure within the plethysmograph.

An occluding pneumatic cuff was placed round the wrist immediately proximal to the plethysmograph and inflated to 40 mm Hg for 10 to 20 seconds: the cuff remained deflated for at least 10 seconds between consecutive inflations.

All pressures were measured with capacitance transducers (Southern Instruments) and recorded with a four-channel direct writing pen unit. The pens were 16 cm long, working in an arc of 4 cm and had a peak-to-peak response time of 0.07 sec. The paper speed usually employed was 5 mm/sec, which allowed hand volume and hand venous pressure to be compared at intervals of 0.2 sec during an episode of venous obstruction.

Expression of results. The increase in hand volume during venous obstruction was expressed graphically against the simultaneous increase in vascular distending pressure. These parameters were measured at intervals of 0.2 to 0.5 sec through the period of venous obstruction. A curve was obtained representing the vascular volume-pressure relationship of the hand during each period of venous occlusion. The gradient of this curve represented change of hand volume resulting from change in vascular distending pressure and was therefore equal to the hand vascular distensibility.

Each volume-pressure relationship presented in this paper represents mean values derived from analysis of twenty consecutive episodes of venous tamponade made under constant conditions, unless otherwise stated.

The vessels investigated by this technique are those which could be distended by the imposed vascular distending pressure: they are therefore those vessels which normally contain blood at a pressure less than the highest vascular distending pressure imposed. As the highest vascular distending pressure was about 30 mm Hg this technique investigates those vessels in which the blood pressure is usually low. As the capacity of these vessels is large they are called the low pressure capacity vessels, and consist of veins, venules and capillaries. The volume of the veins and venules investigated considerably exceeds that of the capillaries (Litter and Wood, 1954).

Oesophageal pressure was used as an index of intrapleural pressure and was measured by the method of Dornhorst and Leathart (1952). The oesophageal catheter was passed pernasally and its oesophageal end adjusted until records of intrathoracic respiratory pressure changes were obtained with minimum cardiac pulsation. The mean oesophageal pressure was obtained from the oesophageal pressure record by determining the area beneath the trace and calculating the height of the rectangle having similar length (duration) and height (pressure).

End-tidal Pco_2 was derived from the record of an infra-red carbon dioxide analyzer (Ird-ometer) sampling continuously at 60 to 120 ml/min from the external end of the patient's tracheostomy tube, or from the mouthpiece of the subject.

The totally paralyzed patients received intermittent positive pressure respiration from an experimental respiration pump (Watson, Spalding and Smith, 1962). The mean intrathoracic pressure was raised by preventing the tracheal pressure from returning to atmospheric pressure during expiration. This was achieved by immersing the outlet of the respiration pump to a known depth in a column of water. The imposed inspiratory tracheal pressure was raised to maintain a constant alveolar ventilation, so that the end-tidal Pco_2 remained constant. Throughout the investigation the respiratory rate was 13/min.

Continuous positive pressure breathing was imposed upon normal subjects by causing them to breathe through a Siebe-Gorman valve placed in an air flow line which was continuously flushed at 50 l./min with air. The pressure within the air flow line was varied by immersing the outlet to a variable depth in a column of water.

Subjects.

Six conscious patients with respiratory paralysis or severe weakness of the muscles of respiration were investigated. Each received IPPR

through a cuffed tracheostomy tube (Spalding and Smith, 1956) which provided an airtight seal in the trachea. Two patients suffering from chronic poliomyelitis had no clinical evidence of disturbance of the control of the circulation and had a normal response of the arterial blood pressure to Valsalva's manoeuvre. Two patients had severe polyneuritis and two patients had complete traumatic lesions of the spinal cord in the cervical region: these four patients had a grossly abnormal response of the arterial blood pressure to the Valsalva manoeuvre. Six normal subjects aged 27 to 39 years were also investigated. All subjects and patients lay down throughout the investigation.

Experimental procedure.

After the apparatus had been set up, no measurement of capacity vessel distensibility was made for about 30 minutes. Twenty consecutive records were then analyzed. After this the mean intrathoracic pressure was raised to the desired level and twenty consecutive records again analyzed. The intrathoracic pressure was then restored to its initial level and further measurement made. This procedure was repeated with different values for mean intrathoracic pressure. Care was taken to keep the end-tidal P_{CO_2} constant in each patient (± 2 mm Hg) throughout these investigations.

All values given here represent the mean values obtained from twenty consecutive episodes of venous tamponade when a steady state had become established. The time taken for the observed changes in distensibility to occur is also described.

RESULTS

Elevation of the mean intrathoracic pressure to 5 cm H_2O caused no change in the vascular volume-pressure relationship of the hand in four of the six normal subjects. Further elevation of the mean intrathoracic pressure caused the capacity vessels of the hand to become less distensible. The results shown in figure 1A were derived from one of these four subjects, and are typical. Elevation of the mean intrathoracic pressure to 5 cm H_2O was associated with a decrease in the distensibility of the capacity vessels of the hand in the two remaining normal subjects. This decrease became more marked when the intrathoracic pressure was further increased. The results shown in figure 1B were derived from one of these two patients. The reduction in distensibility was highly significant ($P<0.01$) on all occasions. Similar significant results were obtained in the two totally paralyzed patients with normal nervous control of the circulation receiving IPPR (figs. 2A, 2B). The distensibility of the capacity vessels began to decrease about 10 seconds after the intrathoracic pressure was increased and had usually attained

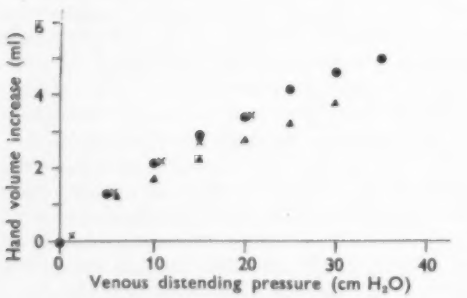

FIG. 1A

● mean oesophageal pressure −1.5 cm H_2O.
× mean oesophageal pressure +5.5 cm H_2O.
▲ mean oesophageal pressure +9.0 cm H_2O.

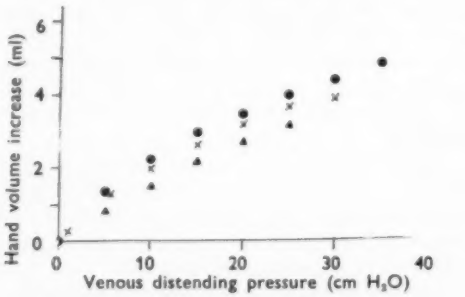

FIG. 1B

● mean oesophageal pressure −1.0 cm H_2O.
× mean oesophageal pressure +4.0 cm H_2O.
▲ mean oesophageal pressure +9.0 cm H_2O.

Examples of mean vascular volume-pressure relationship of the hand in two normal subjects. Each curve was derived from analysis of twenty consecutive periods of venous obstruction, each lasting about 10 seconds.

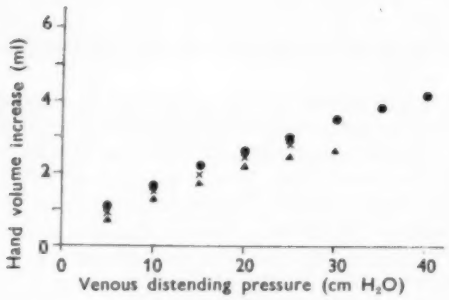

FIG. 2A

● mean oesophageal pressure + 1.0 cm H_2O.
× mean oesophageal pressure + 5.5 cm H_2O.
▲ mean oesophageal pressure +10.0 cm H_2O.

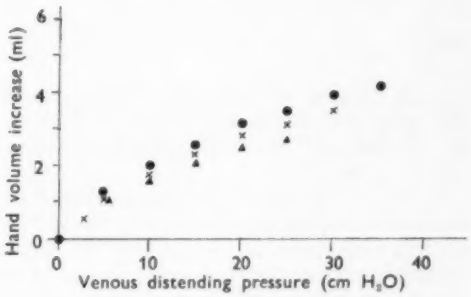

FIG. 2B

● mean oesophageal pressure +1.3 cm H_2O.
× mean oesophageal pressure +5.0 cm H_2O.
▲ mean oesophageal pressure +9.0 cm H_2O.

Examples of mean vascular volume-pressure relationship of the hand in two subjects with respiratory paralysis but with normal nervous control of the circulation. Each curve was derived from analysis of twenty consecutive periods of venous obstruction, each lasting about 10 seconds.

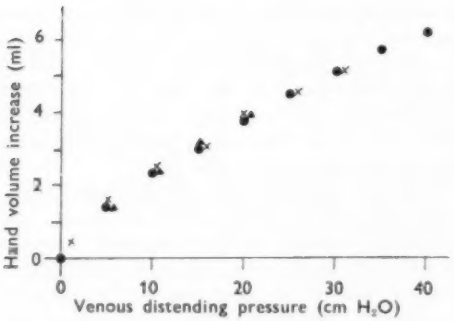

FIG. 3A

● mean oesophageal pressure +0.9 cm H_2O.
× mean oesophageal pressure +5.5 cm H_2O.
▲ mean oesophageal pressure +8.5 cm H_2O.

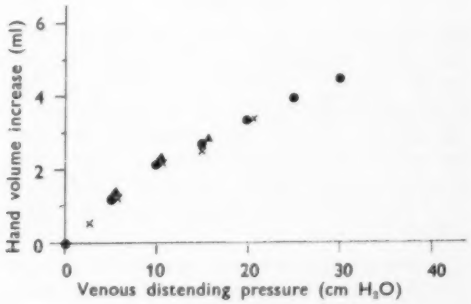

FIG. 3B

● mean oesophageal pressure +1.0 cm H_2O.
× mean oesophageal pressure +5.0 cm H_2O.
▲ mean oesophageal pressure +9.0 cm H_2O.

Examples of mean vascular volume-pressure relationship of the hand in two subjects with severe polyneuritis.

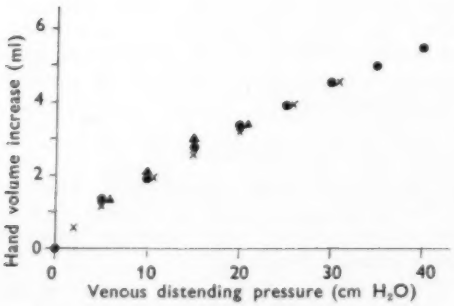

FIG. 4A

● mean oesophageal pressure +1.2 cm H_2O.
× mean oesophageal pressure +4.0 cm H_2O.
▲ mean oesophageal pressure +9.5 cm H_2O.

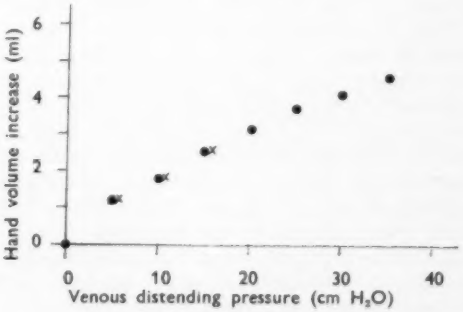

FIG. 4B

● mean oesophageal pressure +1.3 cm H_2O.
× mean oesophageal pressure +5.0 cm H_2O.

Examples of mean vascular volume-pressure relationship of the hand in two subjects with complete traumatic lesion of the cervical part of the spinal cord.

a steady state within 2 minutes. The increase in distensibility of the capacity vessels found when the intrathoracic pressure returned to normal took a similar time.

No change occurred in the distensibility of the capacity vessels of the hand either in the two patients with acute polyneuritis (figs. 3A, 3B) or in the two with complete traumatic lesions of the spinal cord in the cervical region (figs. 4A, 4B), when the mean intrathoracic pressure was raised. These patients were less tolerant of elevation of mean intrathoracic pressure, complaining of faintness with values of intrathoracic pressure less than those tolerated by patients with normal nervous control of the circulation.

DISCUSSION

Blair, Glover and Kidd (1959) found no alteration of the distensibility of the forearm capacity vessels during continuous positive pressure breathing. Ernsting (1957) presented evidence of reduction of venous distensibility of the hand during positive pressure breathing with airway pressures considerably in excess of those investigated here. Neither investigator measured intrathoracic pressure.

In this investigation mean oesophageal pressure is used as representing mean intrapleural pressure. The conclusion of most recent investigators is that the mean oesophageal pressure is 1 to 2 cm H_2O higher than the mean intrapleural pressure in subjects lying supine (Mead and Gaensler, 1959; Knowles, Hong and Rahn, 1959).

The technique used in this investigation is similar to that employed by Sharpey-Schafer (1961) for determining the distensibility of the capacity vessels of the forearm. It is related to the plethysmographic methods of determining "venous" distensibility in vivo (Clark, 1933; Kidd and Lyons, 1958; Glover et al., 1958; Eckstein and Horsley, 1960). The vessels investigated are the low pressure capacity vessels which consist almost entirely of veins (Litter and Wood, 1954). The veins were collapsed by the hydrostatic pressure imposed by the water within the plethysmograph, so that a reasonably constant baseline hand venous volume was assured (Clark, 1933).

During intermittent positive pressure respiration the mean intrathoracic pressure is raised (Opie, Spalding and Smith, 1961). Elevation of the mean intrathoracic pressure imposes a stress upon the circulation by impeding venous return to the right side of the heart (Lauson, Bloomfield and Cournand, 1946; Brecher and Mixter, 1953). The volume of blood displaced into the "vascular deadspace" of the veins by a given rise in venous pressure depends upon the distensibility of the systemic veins. Under normal conditions it is possible that 50–60 per cent of the total blood volume is within the low pressure capacity vessels (Landis and Hortenstine, 1950). If the observations made upon the hand are representative of the systemic muscular veins, the volume of blood pooled in the veins as a result of elevation of intrathoracic pressure during pressure breathing is reduced by the decreased venous distensibility. Patients receiving IPPR who have abnormal nervous control of the circulation do not modify the distensibility of the capacity vessels of the hand in this way. It is therefore probable that the reduction in distensibility is under nervous control and is possibly due to an increase in venomotor tone.

When the mean intrathoracic pressure of conscious patients receiving IPPR is raised, the transmural central venous pressure remains almost unchanged until the mean oesophageal pressure reaches 4 to 6 cm H_2O (Watson, Spalding and Smith, 1962), provided that the nervous control of the circulation is normal. Patients without normal nervous control of the circulation suffer progressive fall in transmural central venous pressure as the mean intrathoracic pressure is raised. It is probable that in patients with normal nervous control of the circulation one of the factors maintaining a constant transmural central venous pressure when intrathoracic pressure is raised is the reduction of systemic venous distensibility.

SUMMARY

The distensibility of the capacity blood vessels of the hand was measured in six normal subjects and in six patients with respiratory paralysis during pressure breathing.

In subjects and patients with normal nervous control of the circulation, pressure breathing was associated with a reduction in distensibility of the capacity blood vessels of the hand.

In patients with demonstrably abnormal

nervous control of the circulation no change was found in the distensibility of the capacity blood vessels of the hand during pressure breathing.

ACKNOWLEDGMENTS

I am greatly indebted to Dr. W. Ritchie Russell, Dr. J. M. K. Spalding and Dr. A. Crampton Smith for the opportunity to study patients under their care and for research facilities. Dr. E. Seelye helped in the presentation of this paper.

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EDITORIAL ANNOUNCEMENT

At the request of readers the index for Volume XXXIII of the *British Journal of Anaesthesia* is incorporated in this issue. It is hoped that this will prove more convenient for our subscribers. A title page for the volume will also be found loose, ready for binding.

Brit. J. Anaesth. (1961), 33, 606

CHANGES IN VASCULAR DISTENSIBILITY OF THE HAND RESULTING FROM ALTERATION OF THE COMPOSITION OF ALVEOLAR AIR

BY

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THE vascular distensibility of the hand was measured in eight normal subjects when the alveolar partial pressures of carbon dioxide and of oxygen were altered.

METHODS

The vascular distensibility of the hand was measured by comparing the increase in hand volume resulting from intermittent obstruction of the venous return from the hand with the simultaneous rise in venous distending pressure of the hand. This technique has previously been described in detail (Watson, 1961).

End-tidal gas was obtained with a Rahn-Otis sampler (Rahn and Otis, 1948) and analyzed with a Lloyd-Haldane apparatus (Lloyd, 1958).

Expression of results. The increase in hand volume during venous obstruction was expressed graphically against the simultaneous increase in vascular distending pressure: these were measured at intervals of 0.2 to 0.5 sec throughout the period of venous obstruction. A curve was obtained representing the vascular volume-pressure relationship of the hand during each period of venous occlusion. Twenty consecutive records obtained under constant conditions were analyzed, and the volume-pressure relationships expressed in this paper represented means of these values. The gradient of the curve expressing the mean volume-pressure relationship represented change of hand volume resulting from change in vascular distending pressure and was therefore equal to the hand vascular distensibility. As the vascular volume-pressure relationship of the hand is curvilinear (fig. 1) it is necessary to measure the gradient of the resulting line at a constant hand volume so that comparable values can be obtained under different circumstances. In all the results presented below, vascular distensibility was measured at a constant hand volume, 2 ml above the resting volume found at the beginning of the investigation.

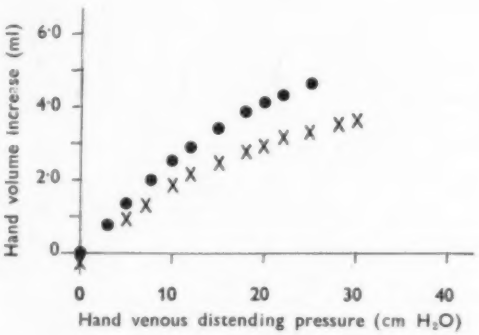

FIG. 1

Vascular volume-pressure relationships of the hand of a typical normal subject.
● Before voluntary over-ventilation.
× During voluntary over-ventilation.
The veins become less distensible during over-ventilation.

Subjects. Eight normal male subjects aged 18 to 40 years were investigated. During the investigation the subject was kept at mental and physical rest but was not permitted to sleep.

Experimental procedure. After the apparatus had been set up, no measurement of vascular distensibility was made for about 30 minutes. The patient then began to inspire air from a polyethylene bag of 100 litres capacity. After fifteen to twenty episodes of obstruction of the hand venous return, the subject began to inspire gas of known compositions from a similar bag. The subject was not aware of the substitution of the bags. Vascular distensibility was again measured.

This investigation was supported by a grant from the National Fund for Research into Poliomyelitis.

Finally, the patient again inspired air from a bag and vascular distensibility was measured until it returned to its previous level. A number of different gas mixtures were investigated in each subject. The subjects also lowered their alveolar P_{CO_2} by deliberate over-ventilation.

RESULTS

Alteration of arterial P_{CO_2}.

Figure 1 shows the vascular pressure-volume relationship of the hand obtained from a typical subject before and during sustained over-ventilation at a constant P_{CO_2}. Each point represents a mean value derived from fifteen to twenty consecutive periods of venous tamponade. The reduction of vascular distensibility found during overventilation was highly significant ($P<0.01$) Figure 2 expresses graphically the values obtained for vascular distensibility from all the subjects against end-tidal P_{CO_2}, both when the end-tidal P_{CO_2} was reduced by sustained, constant over-ventilation, and when it was increased by breathing air-carbon dioxide mixtures. The veins of all subjects became less distensible during overventilation. Venous distensibility increased in four subjects when the end tidal P_{CO_2} was raised, remained unchanged in three, and decreased in one.

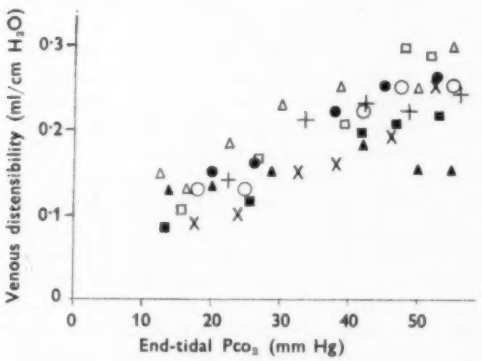

FIG. 2

Vascular distensibility expressed graphically against end-tidal P_{CO_2}. Each symbol represents one subject. The end-tidal P_{CO_2} of the subjects at rest lay within the range 37 to 43 mm Hg; it was reduced by over-ventilation, and increased by inhalation of air-carbon dioxide mixtures. All values represent "steady states".

Alteration of arterial P_{O_2}.

Figure 3A expresses graphically the values obtained for venous distensibility from all subjects against end-tidal P_{O_2}, when the subjects were breathing air, and when they were breathing air-nitrogen mixtures. The low pressure capacity vessels of all subjects became less distensible when the P_{O_2} was reduced to 80 mm Hg or less.

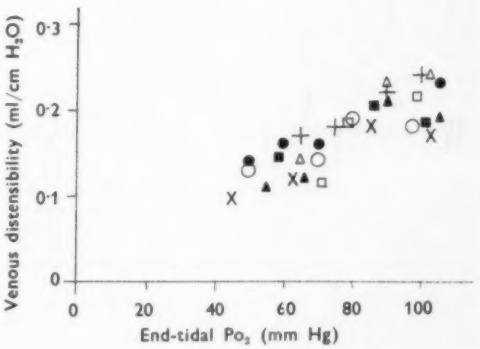

FIG. 3A

Vascular distensibility expressed graphically against end-tidal P_{O_2}. Each symbol represents one subject. The end-tidal P_{O_2} of the subjects breathing air lay within the range 95 to 110 mm Hg; it was reduced by breathing air-nitrogen mixtures. All values represent "steady states".

When 100 per cent oxygen was substituted for inspired air, no change in vascular distensibility was found in any subject.

Most subjects increased their respiratory minute volumes when they became hypoxic. This resulted in a slight fall of end-tidal P_{CO_2}. Following the imposed hypoxia, the patients deliberately continued to over-ventilate so that the end-tidal P_{CO_2} remained at the same level as during hypoxic over-ventilation. Vascular distensibility was measured under these circumstances (fig. 3B). In all subjects the vascular distensibility was significantly less during hypoxia ($P<0.05$) than during voluntary over-ventilation although the end-tidal P_{CO_2} was the same (± 2 mm Hg) on both occasions. This indicates that hypoxia itself decreased the vascular distensibility and that the reduction in distensibility was not simply due to reduction of alveolar P_{CO_2} by hypoxic over-ventilation.

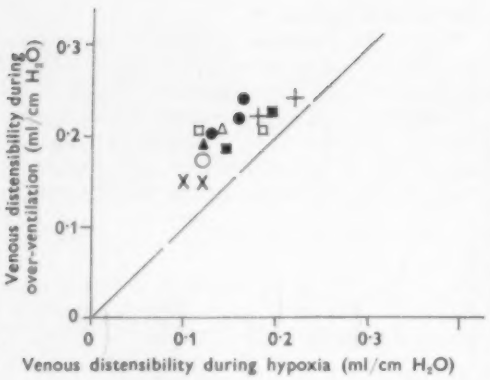

FIG. 3B

The vascular distensibility of each subject measured during voluntary over-ventilation is expressed against the vascular distensibility of the same subject when involuntary over-ventilation was induced by hypoxia. Each symbol represents a different patient. Although end-tidal P_{CO_2} was the same in a given subject both during voluntary over-ventilation and during over-ventilation induced by hypoxia, the vessels of all subjects were found to be less distensible during hypoxic over-ventilation.

DISCUSSION

The technique used in this investigation for measuring the distensibility of the capacity vessels of the hand is similar to that employed by Sharpey-Schafer (1961) for determining the distensibility of the capacity vessels of the forearm. It is related to the plethysmographic methods of measuring venous distensibility in vivo (Clark, 1933; Kidd and Lyons, 1958; Glover et al., 1958; Eckstein and Horsley, 1960) but represents an improvement on these methods as changes in venous distensibility can be followed with greater rapidity. The vessels investigated are the low pressure capacity vessels which consist principally of veins (Litter and Wood, 1954). These vessels were collapsed by the imposed hydrostatic pressure of the water within the plethysmograph so that a reasonably constant baseline hand venous volume was assured (Clark, 1933). It is probable that the changes in vascular distensibility observed are a consequence of alteration of venous tone.

Although the use of end-tidal P_{CO_2} as an indication of arterial P_{CO_2} is justifiable in subjects with normal lungs, end-tidal P_{O_2} is an unreliable index of arterial P_{O_2} because of a significant alveolar-arterial P_{O_2} gradient, the magnitude of which varies with the alveolar P_{O_2} (Lilienthal et al., 1946). The end-tidal P_{O_2} measured was almost certainly higher than the arterial P_{O_2} and the severity of the imposed hypoxia was most probably greater than the end-tidal P_{O_2} would indicate.

Ewald (1873) (quoted by Henderson, 1908) noted a fall in dogs' blood pressure during over-ventilation. Burnham, Hicks and McIntosh (1954) showed that voluntary over-ventilation resulted in a significant increase in cardiac output and a reduction of peripheral resistance. They found no change in central venous pressure in most subjects. A significant decrease of venous distensibility occurred in all subjects in this investigation. If the changes observed in the hand are typical of those occurring in the systemic muscular veins as a whole, a reduction of venous volume, or an increase in venous pressure must occur. Similar changes have been observed in the forearm (Eckstein, Hamilton, McCammond, 1958) although the deep veins of the forearm draining muscle are not themselves muscular. Elevation of arterial P_{CO_2} resulted in an increase of venous distensibility in half the subjects, indicating that the volume of blood held in the systemic veins had increased or that a fall in systemic venous pressure occurred.

During hypoxia, the observed reduction of venous distensibility was probably due to an increase in venous tone and indicated either that a fall in hand venous volume had occurred, or that venous pressure had increased. This effect was due to reduction of alveolar P_{O_2} and was not a consequence of reduction of end-tidal P_{CO_2} by hypoxic over-ventilation. Such a decrease in the distensibility of the capacity vessels could lead to marked redistribution of the blood volume. Fishman et al. (1955) suggested that pulmonary arterial distension found during hypoxia resulted from a shift of blood from the systemic vessels into the lungs. The present findings and those of Eckstein and Horsley (1960) are compatible with this hypothesis.

SUMMARY

The venous distensibility of the hand was measured in eight normal subjects and the arterial partial pressures of respiratory gases were altered.

Over-ventilation reduced the venous distensibility of the hand in all subjects. Elevation of the arterial Pco_2 caused an increase in venous distensibility in four subjects.

Lowering the arterial Po_2 caused the venous distensibility of the hand to decrease. When oxygen was substituted for inspired air, no change in venous distensibility was found.

ACKNOWLEDGMENTS

I am greatly indebted to Dr. W. Ritchie Russell, Dr. J. M. K. Spalding and Dr. A. Crampton Smith for the opportunity to study patients under their care, and for research facilities. Dr. E. Seelye helped in the presentation of this paper.

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Brit. J. Anaesth. (1961), **33**, 610

THE EFFECTS OF EXTERNAL RESISTANCE TO RESPIRATION

PART II: RESISTANCE TO RESPIRATION DUE TO ANAESTHETIC APPARATUS

BY

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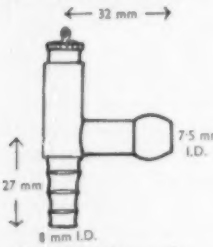
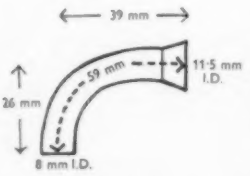
The purpose of this investigation was to measure and compare the resistances to steady gas flows, and to the varying gas flows occurring during normal respiration, of some commonly used anaesthetic apparatus. A preliminary study of the pressure-flow characteristics of semiclosed anaesthetic breathing systems has also been made. The items of equipment investigated were: a Magill attachment consisting of a reservoir bag, a corrugated rubber tube with its end fitting and a Heidbrink expiratory valve; an endotracheal catheter mount; a No. 4 Cobb suction union; a No. 9 curved Magill endotracheal connector*; a No. 10 endotracheal tube and a Coxeter expiratory valve. These items were considered individually, connected together and assembled to form the equivalent of semiclosed anaesthetic systems.

The effect of each arrangement upon the respiratory pattern of a conscious seated subject was recorded. These records were not analyzed in detail but the peak flow rates should give an indication of the gas flows that anaesthetic apparatus should be capable of accepting without undue impediment.

*The dimensions of the Cobb suction union and of the Magill endotracheal connector are shown in the accompanying figures.



Cobb suction union.



Magill endotracheal connector.

Mushin and Mapleson (1954) observed that the opening pressure of the expiratory valve in a Magill semi-closed system needs to be sufficient to expand and fill the reservoir bag. A greater pressure is not necessary; it may be harmful. The pressure required to fill the reservoir bag used in this investigation was therefore measured under both static conditions and under dynamic conditions equivalent to those under which it would be used in clinical practice.

The same subject was used throughout the investigation as a source of variable respiratory flow. The airflow resistance of his nose and nasopharynx was determined in order to put the measured resistances of the anaesthetic equipment into perspective.

REVIEW

Resistance to airflow through anaesthetic apparatus is usually measured in terms of the pressure gradient occurring across it during the maintenance of a known airflow through it. Nearly all the measurements reported in the literature have been made under steady flow conditions (Macon and Bruner, 1950; Gaensler, Maloney and Björk, 1952; Orkin, Siegel and Rovenstine, 1954, 1957; Mushin and Mapleson, 1954; Bullough, 1955; Galloon, 1957; Macintosh, Mushin and Epstein, 1958; Chandler, 1958).

The experimental method described by Gaensler, Maloney and Björk (1952) has been adopted by subsequent workers. They arranged for a steady airflow to be supplied to the item under investigation through a large container, the other end of the item being open to atmosphere. The pressure gradient between the container and the atmosphere, that is, across the anaesthetic item, was measured while a steady

known flow was passed through it. An advantage of this method, as observed by Macintosh, Mushin and Epstein (1958), is that since the linear velocity of the air passing through such a container is small, the pressure changes due to kinetic effects are negligible.

Orkin, Siegel and Rovenstine (1954, 1957) concluded that the overall resistance of combinations of anaesthetic equipment equalled the sum of the resistances of their individual components. This has not been a universal finding. Bullough (1955), for example, found that the resistance of a Cobb endotracheal connector was reduced by connecting an endotracheal tube to it. Macintosh, Mushin, and Epstein (1958) noted that the overall resistance of an endotracheal tube combined with a connector was usually less than the sum of the individual resistances.

Macintosh, Mushin and Epstein (1958) drew attention to the inadequacy of measurements made under steady flow conditions as an indication of the resistance to the intermittent flows that occur during respiration. Little work, however, appears to have been done on the measurement of the resistance to airflow through anaesthetic apparatus under varying flow conditions. Hunt (1955) compared the resistances of disc valves and of canisters under steady flow and under varying flow conditions. He found close agreement between the measurements of resistance made under the two sets of conditions. The variable flow was generated using a variable stroke plunger in a cylinder and a specially cut cam. The variations in flow so produced were not as rapid as the rate of change of flow that may occur during normal respiration. The flows were calculated from the speed of the driving motor and the instantaneous position of the piston. A capacitance pressure transducer was used for pressure measurements under varying flow conditions.

THE PRESENT INVESTIGATION

Apparatus.

Rotameter flowmeters, a U-tube water manometer and an inclined manometer were used for measurements under steady flow conditions.

For measurements under respiratory flow conditions Vickers Research Limited pressure and flow transducers were used in conjunction with a Respiratory Analyser (Scott and Williams, 1960; Williams, 1960). The ranges of the capacitance-type pressure transducers were ± 25 cm H_2O, ± 7.5 cm H_2O and ± 0.5 cm H_2O. The pressure gradient across the flow transducer (pneumotachograph head) bears a linear relationship to the flow passing through it up to flows of 200 l./min, at which the pressure across it is 0.5 cm H_2O. The flow transducer was therefore used in conjunction with the ± 0.5 cm H_2O pressure transducer. (The application of various forms of pneumotachograph head to the measurement of flow during anaesthesia has been discussed by Hill, 1959.) The characteristics of the Vickers Research Limited flow transducer are not altered by the condensation of water from expired air since the plates of the flow resistance element are made of hydrophobic material and they are well spaced. Electrical heating of the transducer is therefore unnecessary. The Respiratory Analyser provides output voltages directly proportional to the pressures and flows being measured. (It also provides output voltages proportional to volume, by electronic integration of "flow" voltages with respect to time; to work, by the electronic integration with respect to time of the product of "flow" and "pressure" voltages, this product being obtained by servo-multiplication; and to rate of work. These latter facilities were not used in this investigation.) A switch associated with each of the four output channels enables any of the above parameters to be chosen at will for display or for recording. In this investigation records were obtained by photographing the display on a double beam oscilloscope. The Respiratory Analyser and associated transducers were calibrated by applying known pressures and flows, measured by the same Rotameters and manometers as were used for the steady flow measurements, to the appropriate transducers.

An air pump was used for generating airflow in either direction for the steady flow experiments and for calibration of the flow transducer.

The basic method of pressure and flow measurement.

The method of Gaensler, Maloney and Björk (1952) was not used because the deadspace in the large container would have been excessive

for the respiratory flow experiments. A method equally suitable for measurements under both respiratory flow and steady flow conditions was needed.

A symmetrical arrangement was tried. Tubes of equal length were fitted snugly over each end of the anaesthetic item. A simple pressure tapping was made in each tube. For steady flow measurements known airflows were passed into the open end of one tube and the corresponding pressure differences between the pressure tappings were measured using the appropriate manometer. For measurements under respiratory flow conditions the subject breathed through the flow transducer into the open end of the same tube, the appropriate pressure transducers being used in conjunction with the Respiratory Analyser for flow and pressure measurements. Using this method it was found that consistent results could be obtained during a given experiment. Examples are shown in figure 1. Even under steady flow conditions, however, the results were not repeated quantitatively from day to day. They were found to be dependent upon the precise way in which the experiment was set up, particularly with regard to the pressure tappings. The method was abandoned.

It was decided to make all pressure measurements relative to atmosphere and to make them always from the same pressure tapping. One of the carefully designed pressure tapping points incorporated in the flow transducer was used for the purpose. Anaesthetic items were arranged only as they might be connected in actual use. The flow transducer was connected to the anaesthetic item, or system, at the end which would normally be in direct communication with the patient's airway. For making the connection between the flow transducer and the endotracheal tube a special connector was drawn from glass tubing, one end having the same internal diameter as the entrance to the flow transducer and the other end being made just large enough to accommodate the end of the endotracheal tube.

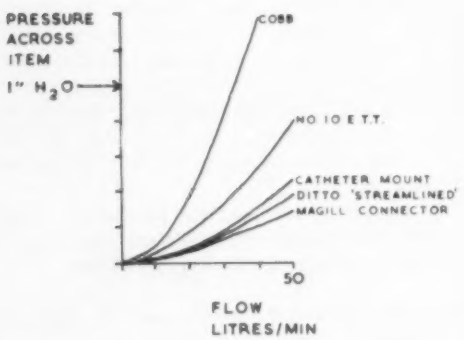


FIG. 1

The resistance to airflow through some items of anaesthetic equipment. E.T.T.=endotracheal tube.

For measurements under steady flow conditions air was blown into and sucked out of the flow transducer via a Rotameter. The pressure tapping on the flow transducer nearest to the anaesthetic apparatus was connected to a manometer for measurement of the pressure gradients across the apparatus corresponding to the known flows passing through it. The second flow transducer pressure tapping was occluded to prevent air leakage.

For measurements under respiratory flow conditions a conscious seated subject breathed into the open end of the flow transducer using either a mouthpiece consisting of a short wide bore tube, his nose being clipped, or a standard anaesthetic facepiece. Pressure and flow were recorded continuously. The same pressure tapping was used for pressure measurements under respiratory flow conditions as was used during the steady flow experiments. The tubing used to connect the pressure tapping points to the pressure transducers was kept as short as possible and each tube was cut to the same length. During the course of each series of measurements the dynamic measuring equipment was calibrated for flow rate in both directions and for pressures above and below atmospheric pressure.

RESULTS

The pressure-flow characteristics of tubular items under steady flow conditions.

Using the above arrangement the characteristics of the flow transducer plus the glass connector were determined. Steady flows in both directions, in increments of 10 l./min. up to 100 l./min., were passed through the system while corresponding pressures were measured. The end of the endotracheal tube (size 10) was then inserted into

the open end of the glass connector and the pressure measurements were repeated, using the same flows as before. These measurements were repeated as the Magill endotracheal connector (size 9), the rubber tubing of the catheter mount, the metal fitting of the catheter mount and the Heidbrink valve were each in turn added to the system. Finally a further series of measurements were made using the Cobb suction union (No. 4) in the system instead of the Magill endotracheal connector. This arrangement has the advantage of measuring all resistances from the standpoint of a subject breathing through the apparatus, and resistance and streamlining effects at the junctions between the items of anaesthetic equipment are automatically included in the measurements. The results are shown in figures 2 and 3.

By taking the differences between successive pressure readings at a given flow rate, the contribution of each item to the resistance of the system may be derived. These values indicate the resistance offered by each item only in the context of the particular arrangement described, which is also the arrangement in which it would be employed in clinical practice. The derived characteristics are shown in figure 4. The values plotted were obtained from experiments carried out on two entirely separate occasions between which all the apparatus had been dismantled. They indicate how constant are the results of repeated experiments carried out by this method.

The pressure-flow characteristics of the corrugated tube and reservoir bag fitting were then determined with the reservoir bag tap open. The same general method as above was used except that the tubing was connected directly to the flow transducer, the glass connector being omitted. At a flow rate of 100 l./min the pressure between the ends of the tube lying straight upon a bench was 0.25 in. H_2O (0.6 cm H_2O). Connection of the reservoir bag and end fittings increased this to 0.4 in. H_2O (1 cm H_2O). At 45 l./min the resistance of the corrugated tube, reservoir bag and end fittings was only 0.1 in. H_2O (0.25 cm H_2O). These pressures are very small in relation to the pressures,

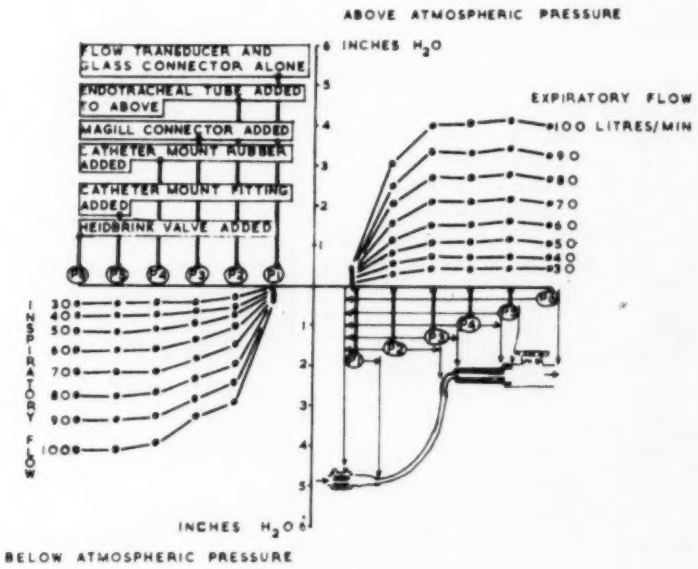


FIG. 2

The resistance to airflow through items of anaesthetic equipment, measured as each individual item is added to form an assembly incorporating a Magill endotracheal connector.

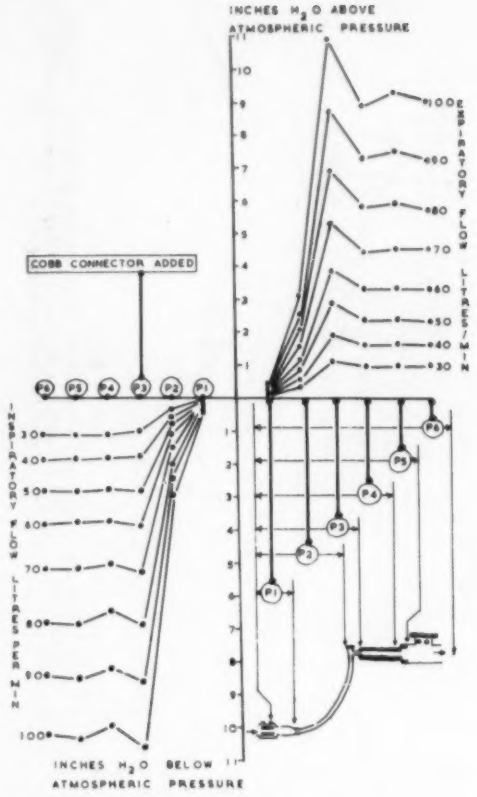


FIG. 3

As figure 2, but using a Cobb suction union in place of the Magill endotracheal connector.

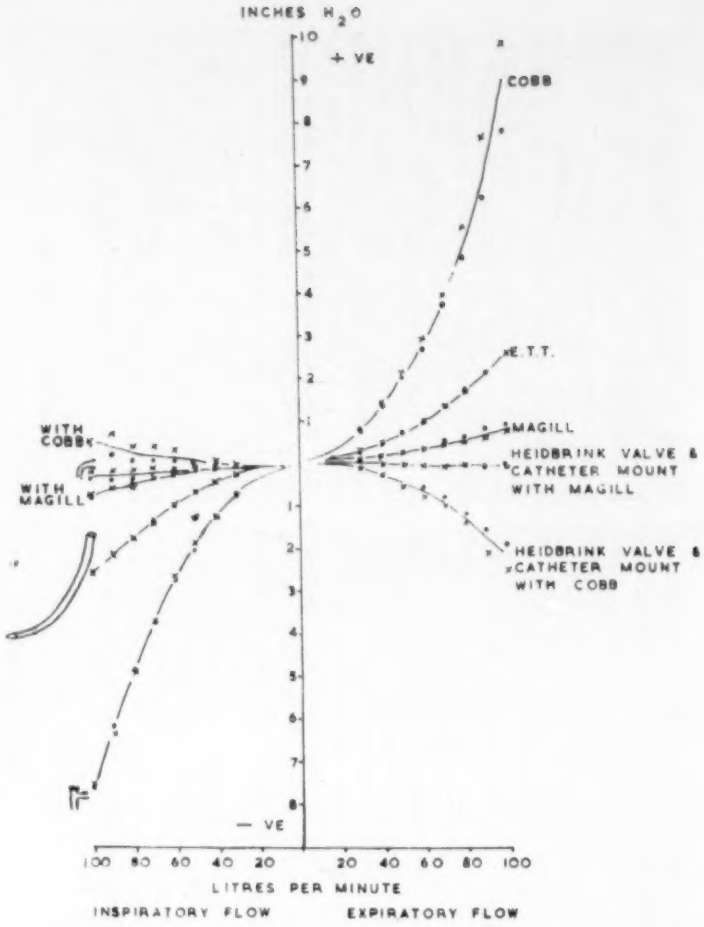


FIG. 4

The effective resistance to airflow through individual items of anaesthetic equipment when assembled; derived from the values given in figures 2 and 3 by subtraction of successive pressure readings at given flows. E.T.T.=endotracheal tube.

developed at comparable flow rates, across items of anaesthetic equipment to which the tubing is usually connected.

The pressure-flow characteristics of tubular items under respiratory flow conditions.

The same assembly and arrangements of anaesthetic equipment were re-examined under respiratory flow conditions, measurements being made by the basic methods described above. The seated subject relaxed as much as possible and breathed quietly through the open end of the flow transducer. When respiration had become stable, continuous recordings were made of pressure and flow while breathing through each arrangement of the equipment. Recording was then continued while the subject varied the amplitude of his respiration. The measurements of pressure and flow under steady flow conditions were repeated before disturbing the assembly and these measurements were used for comparison with those obtained under respiratory flow conditions.

Any phase difference between the recorded peak flows and the corresponding peak pressures was negligible. For each arrangement of the equipment peak flows were plotted against the simultaneously recorded peak pressures together with the values for flow and pressure obtained under steady flow conditions. For all practical purposes the characteristics determined under the two sets of conditions were identical. Three examples are given. Figure 5 shows the characteristics of the

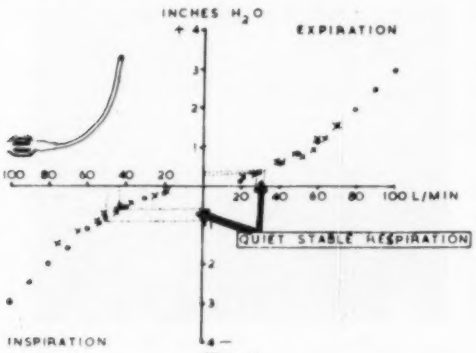


FIG. 5

A comparison of the resistance to airflow through one end of the flow transducer plus the glass connector plus the endotracheal tube, as measured under steady flow (points) and under respiratory flow conditions (crosses).

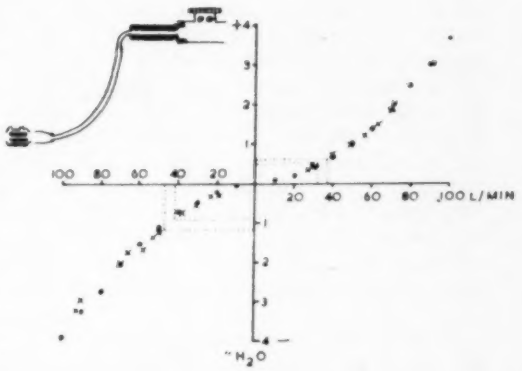


FIG. 6

As figure 5, but for the complete assembly of anaesthetic equipment incorporating the Magill connector.

end of the flow transducer plus the glass connector plus the endotracheal tube. Figures 6 and 7 show the characteristics of the complete assembly using the Magill endotracheal connector and the Cobb suction union respectively. The range of values recorded during quiet stable respiration is indicated. Typical respiratory flow and pressure patterns are shown in figure 8.

Although the pressure and flow peaks appear to occur simultaneously and to be consistent with the pressure-flow characteristics determined under steady flow conditions, it does not necessarily follow that the same correlation applies throughout the respiratory cycle. Two records of simultaneous pressure and flow, each of a complete respiratory cycle, were examined in detail. Both records were made while the subject was breathing through the assembly described above, one including the Magill endotracheal connector and the other the Cobb suction union. Simultaneous pressures and flows occurring at a number of instants during each cycle were measured. They are shown plotted in figure 9. The previously determined pressure-flow characteristics, as indicated in figures 6 and 7, are shown as broken lines. It can be seen that during the first part of each half-cycle, while pressure and flow are increasing rapidly, the measured pressure rises more rapidly relative to the simultaneously measured flow than would be expected from the results of the previous experiments. During the second part of each half-cycle, while pressure and flow are waning more gradu-

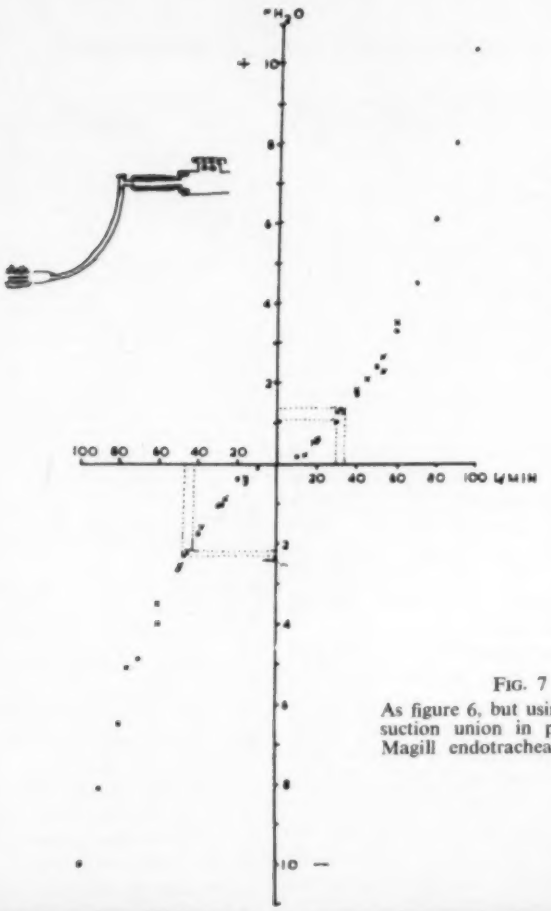
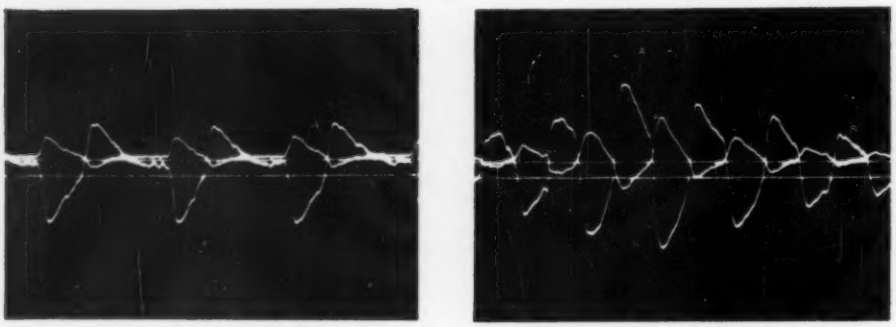


FIG. 7

As figure 6, but using the Cobb suction union in place of the Magill endotracheal connector.



(i) (ii)

FIG. 8

The pressure and flow patterns obtained while breathing through the assembly using the Magill endotracheal connector (i) during quiet steady conditions, the respiratory pattern hardly changing from breath to breath, and (ii) when the amplitude of respiration was voluntarily varied in order to derive the relationship between flow rate and pressure under respiratory flow conditions. (The calibration for the two records is identical.)

Upper trace: pressure (downward deflections, positive).
Lower trace: flow (downward deflections, inspiration).

ally, the pressure-flow characteristics follow almost exactly those previously determined.

A less laborious method of demonstrating the instantaneous variations of pressure-flow relationships throughout a respiratory cycle is to feed the output voltages from the Respiratory Analyser, which are proportional to the flows and pressures being measured, to the X and Y terminals of the oscilloscope. If the same pressure-flow characteristic curve applies throughout the respiratory cycle, then this curve will be described on the cathode ray tube as a single curved line. If the pressure-flow characteristics vary during the respiratory cycle, then "loop" patterns will be formed. Examples of such loops are shown in figure 10. They may be compared with the loops in figure 9.

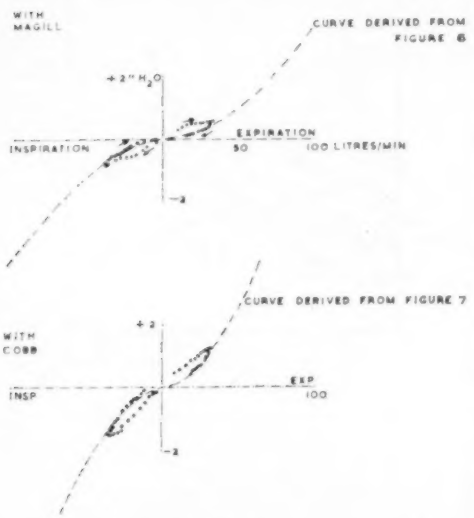


FIG. 9

The pressure-flow characteristics during single respiratory cycles compared with those derived from steady flow and from peak flow measurements.

The deviations from the steady flow characteristics occur in the direction that might be expected. Since a pressure drop must occur between the ends of the system before air can flow through it, a relatively greater pressure might be expected during the initial rapid acceleration of the airflow. There appears to be time for conditions to stabilize during the peak period. The subsequent flow deceleration is less rapid.

The deviations are small during slow quiet respiration of the subject used in these experiments. With more rapid respiration the deviations are increased. It is possible that some of the discrepancy may be due to the method of measurement which was used. More work is required before attempting full evaluation of these loops.

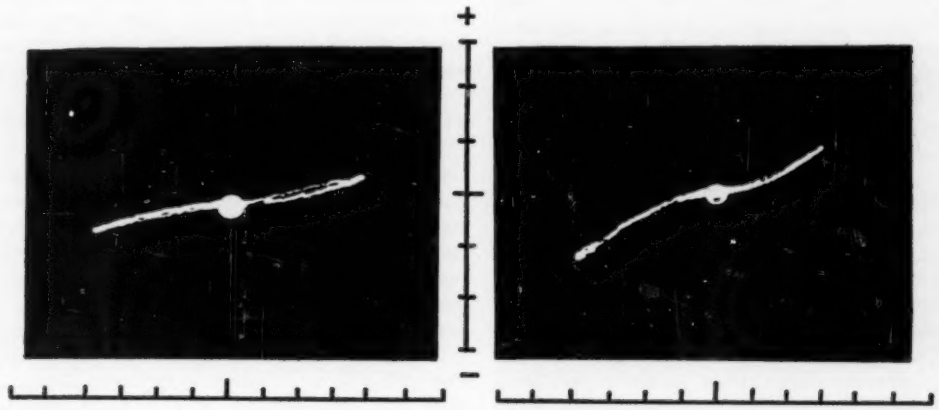


FIG. 10

The flow-pressure loops produced during single respiratory cycles while breathing through an assembly of anaesthetic items including first a Magill endotracheal connector (left), and then a Cobb suction union (right).
Vertical scale ± 3 in. H_2O. Horizontal scale ± 60 l./min.

Controlled conditions of gas flow acceleration and deceleration should be used and the frequency response of the complete measuring system, including transducers, tubing and connections, should be compared with the speed of events occurring during the respiratory cycle.

The pressure-flow characteristics of expiratory valves.

For the measurement of the characteristics of expiratory valves under steady flow conditions the method used was similar to that described by Mushin and Mapleson (1954). A cork occluded one end of the expiratory valve mount. Air was blown into the other end at known flows via a Rotameter and the flow transducer. The pressures developed in the system at the known flows were measured.

For measurements under respiratory flow conditions a 1-inch-diameter Y-piece was added to the system. The stem of the Y was connected to the flow transducer. A very light non-return valve was connected to one limb of the Y and the expiratory valve was connected to the other limb. The subject breathed into the flow transducer. The non-return valve opened on inspiration. It closed on expiration so that air could be expired only through the expiratory valve.

The Heidbrink valve was opened fully and its pressure-flow characteristics were measured under both steady and respiratory flow conditions. Peak flow and pressure values were taken for the latter and care was taken not to disturb the valve setting between readings. The valve was then closed by half a turn at a time and measurements were repeated at each new valve setting. Two and a third turns were required to close the valve completely. The results are shown in figure 11.

The control setting on the Coxeter valve is graduated from 0 to 8. The characteristics of this valve, under both sets of conditions, were measured with the valve fully open and when the control was set to positions 1, 2 and 3 only. The results are shown in figure 12.

By allowing the pressure within these valves to build up very slowly it can be shown that there is variation in the opening pressure for a given setting. Sometimes the Heidbrink valve appeared to open in two distinct steps. Such effects are due to friction. But despite such variations, the agreement between the characteristics determined

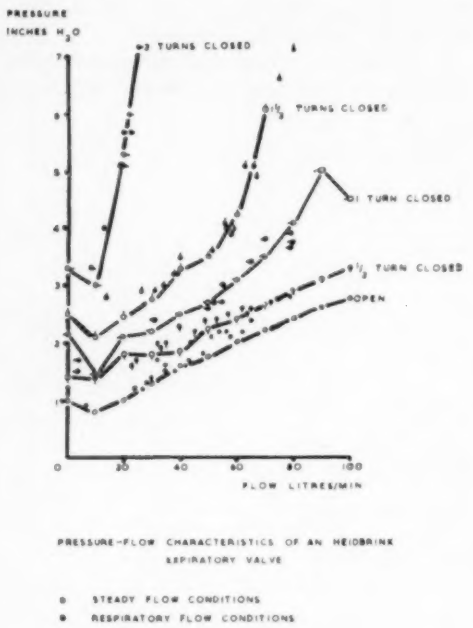


FIG. 11

under the two sets of conditions is close. Any differences between the characteristics found under steady flow and respiratory flow conditions are unlikely to be of practical importance in the context of their present use. This is in agreement with the conclusions of Hunt (1955).

The pressure-volume characteristics of a reservoir bag.

One end of the reservoir bag fitting was occluded by a cork. The reservoir bag was emptied by external compression and the tap was closed. A calibrated, manually operated piston pump was connected to the other end of the reservoir bag fitting. The tap was opened, a known volume of air was injected into the bag, and the tap was closed again. The pump was removed and in its place a cork was inserted. This cork was pierced by a pressure tapping which was connected to an inclined manometer. The tap was opened and the pressure within the system was measured. This procedure was repeated using various known volumes of air. The

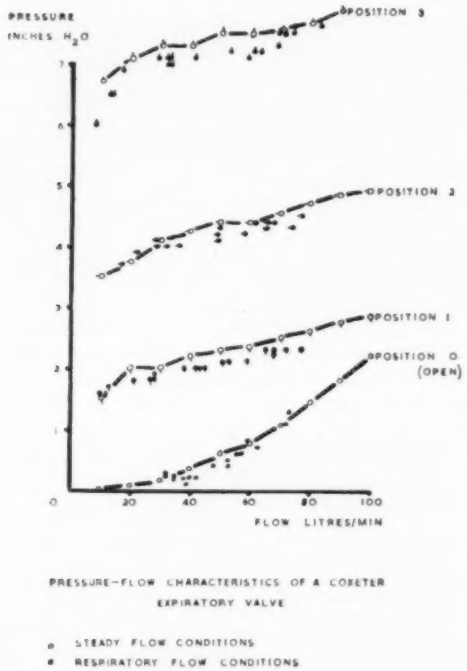


FIG. 12

plotted characteristics are shown in figure 13. They are similar to those shown by Mapleson (1954).

The pressure required to fill the bag under dynamic conditions was then measured. A semi-closed breathing system was used. The arrangement was similar to the standard Magill circuit except that the usual Heidbrink expiratory valve was replaced by a light non-return valve. The subject breathed quietly into the facepiece while the system was supplied with air at 15 l./min. The non-return valve was then loaded with just sufficient weight of plasticine for the opening pressure to be enough to allow the reservoir bag to fill comfortably during each expiration. A length of 3-mm-diameter p.v.c. tubing was inserted into the reservoir bag and connected to the ± 0.5 cm H_2O pressure transducer for these measurements. The pressure within the reservoir bag was measured continuously. No peak pressure greater than 0.1 in. H_2O (0.25 cm H_2O) was recorded.

THE RESISTANCE TO FLOW THROUGH A NOSE NASOPHARYNX

The subject breathed through the nose into a facepiece. Airflow through the facepiece was measured using the flow transducer. An open glass tube, bent to a convenient angle, was held in the closed mouth of the subject, as far back into the mouth as he could tolerate. The other end of the tube passed through an airtight seal in the facepiece. Differential pressure between the glass tube and the facepiece was recorded continuously and simultaneously with airflow. This pressure was taken as representative of the pressure drop across the nose and nasopharynx. The subject varied the amplitude of his breathing.

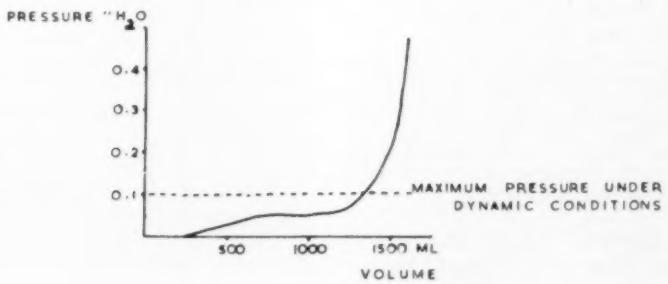
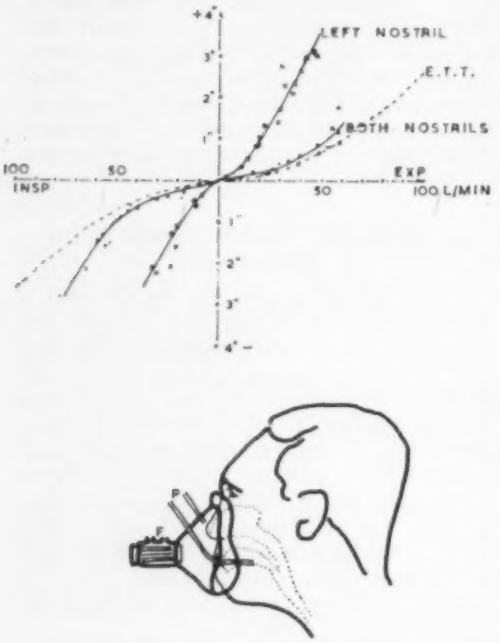


FIG. 13

The pressure-volume characteristics of a reservoir bag under static and under dynamic conditions.

Peak values are plotted in figure 14. The experiment was repeated while each nostril was occluded in turn. The resistance through the left nostril was much greater than that through the right. The resistance through the right nostril was close to that through the whole nose. There was little change in the resistance after the instillation of 0.25 per cent phenylephrine nasal drops.



AIRFLOW RESISTANCE OF A NOSE

FIG. 14

The airflow resistance through the nose and nasopharynx. The differential pressure between the facepiece and the glass tube held in the closed mouth (and communicating with the pharynx) was measured continuously and simultaneously with airflow. Peak values have been plotted. The pressure-flowrate characteristics of a No. 10 endotracheal tube (E.T.T.) have also been plotted for comparison.

Consistent results were not obtained until it was realized that there was a tendency for the facepiece to compress the nose, thereby causing a significant increase in the resistance to airflow. It was necessary to distort the shape of the facepiece. The effects of compressing the soft parts of the nose should evidently receive careful consideration in facepiece design.

A preliminary study of anaesthetic breathing systems

A preliminary study has been made of anaesthetic breathing systems. The results have not been fully evaluated, nor has it been decided which are the best parameters to record and describe when assessing the flow mechanics of such systems. Some of the methods available are indicated.

It has been assumed that a complete anaesthetic breathing system can only be assessed properly under dynamic working conditions, although it is not denied that important points may be deduced from the steady flow characteristics of the component items. The dynamic flow and pressure measurements were made between the mouth of the subject and the breathing system being studied.

A Magill attachment was supplied with air at 15 l./min. The reservoir bag was included in the circuit. The subject breathed either into the facepiece or into the endotracheal tube. The latter was connected using both the Magill endotracheal connector and the Cobb suction union in turn. Various settings of the Heidbrink expiratory valve were tried.

To reproduce conditions comparable with those occurring in dental anaesthesia the Magill attachment was supplied with air at 50 l./min. The subject breathed through the facepiece only. The system was tried both with and without the reservoir bag and with various settings of both the Heidbrink and Coxeter expiratory valves.

A cock placed in series with the air supply from the air pump was adjusted to give the above flow rates. A Rotameter was used for their measurement. It was noted that while using this arrangement the supply flow rate sometimes fell by about 5 l./min during expiration.

Figure 15 shows examples of pressure and flow patterns obtained when using the Magill semi-closed systems. It can be seen that the inclusion of the reservoir bag causes a phase shift between the peak pressure and the peak flow changes as measured at the mouth. During expiration the subject meets with relatively little resistance until the reservoir bag has been filled. High flows

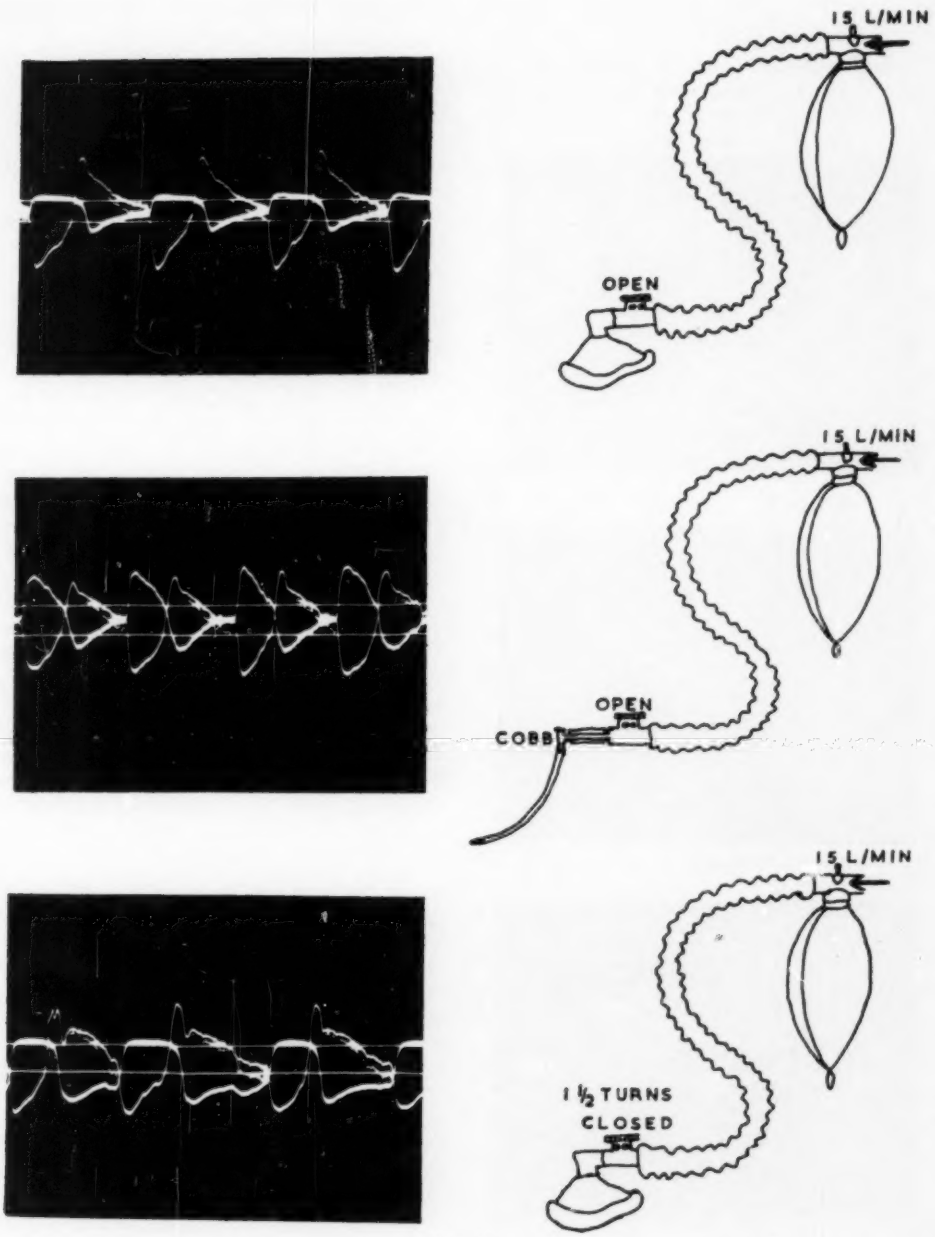


FIG. 15

Examples of the pressure and flow patterns obtained while breathing quietly into semi-closed anaesthetic breathing systems.
Upper (thicker) trace: pressure (downward deflections, positive).
Lower trace: flow (downward deflections, inspiration).

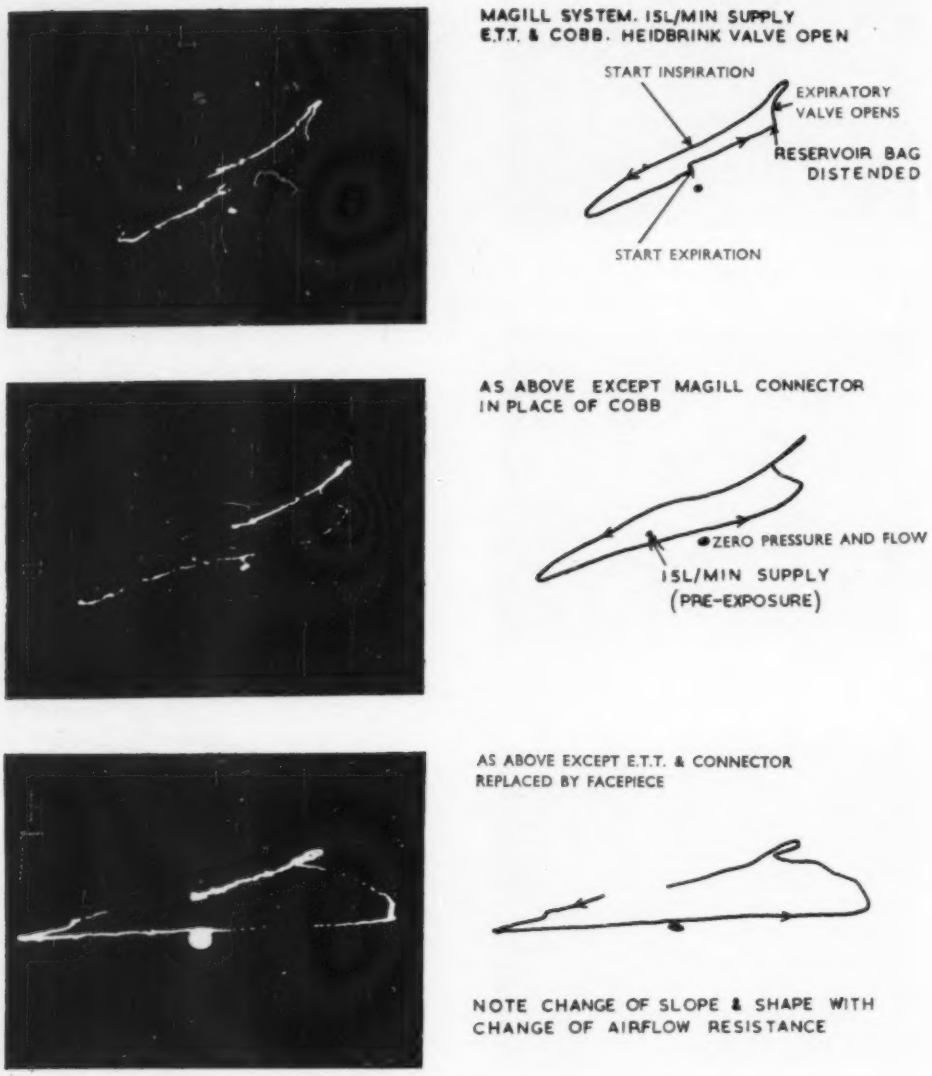

MAGILL SYSTEM. 1SL/MIN SUPPLY
E.T.T. & COBB. HEIDBRINK VALVE OPEN
START INSPIRATION
EXPIRATORY VALVE OPENS
RESERVOIR BAG DISTENDED
START EXPIRATION
AS ABOVE EXCEPT MAGILL CONNECTOR IN PLACE OF COBB
ZERO PRESSURE AND FLOW
1SL/MIN SUPPLY (PRE-EXPOSURE)
AS ABOVE EXCEPT E.T.T. & CONNECTOR REPLACED BY FACEPIECE
NOTE CHANGE OF SLOPE & SHAPE WITH CHANGE OF AIRFLOW RESISTANCE

FIG. 16

The flow-pressure loops obtained while breathing into semiclosed anaesthetic breathing systems. The calibration is the same as in figure 10. E.T.T.=endotracheal tube.

are possible during this initial expiratory period. The flow rate then drops while the pressure rises until the expiratory valve opens, when there may be a second expiratory peak flow.

The pressure and flow patterns vary both with the subject's respiratory pattern when breathing into the system and with the precise arrangement of the apparatus. It is evident that under these circumstances it is of relatively little value to relate peak flows with the out-of-phase peak pressures. With careful interpretation the patterns of the flow changes considered together with the corresponding patterns of pressure change are more informative.

The flow-pressure loop obtained over a single respiratory cycle, as described above, probably gives an even more revealing picture of the events happening within that cycle. Some examples, with key diagrams, are shown in figures 16, 17 and 18. The shapes during inspiration and during the early part of expiration depend upon the airflow resistance of the equipment and upon the supply flow rate. The greater part of the flow-pressure loop pattern formed during expiration is governed by the characteristics of the expiratory valve, and the supply flow rate. If the reservoir bag empties, or if the inspiratory flow exceeds the supply flow rate when the reservoir bag is not used, then a sharp negative pressure change may be seen at the peak of inspiration.

DISCUSSION

Some of the fundamental considerations in the design and the selection of anaesthetic equipment have been stressed by those workers cited above who have made valuable contributions towards the measurement of airflow resistance. It is surprising how much of this good advice appears to have been ignored. The Cobb suction union provides an example. Many of the above workers have commented adversely upon this particular item or upon similar right-angled connectors. Criticism of it is either made or implied in modern textbooks of anaesthesia. Yet this item is still used. It is still sufficiently popular for it to be manufactured and displayed for sale. No special apparatus is needed in order to demonstrate its resistance to airflow. All that is necessary is to breathe through it. Not only can the resistance then be experienced but the turbulence can be heard. The blurring during the peak inspiratory period of the flow-pressure loop shown in figure 18B is due to turbulence caused by the Cobb connector, despite damping in the endotracheal tube connected between it and the flow transducer.

Mushin and Mapleson (1954) observed that the opening pressure of the expiratory valve used in the Magill semiclosed system needs to be sufficient only to fill the reservoir bag. It was evident from their results, as it is from the present investigation, that the minimum opening pressure when using the Heidbrink valve fully open is far in excess of that needed. Yet this is one of the more commonly used valves in inhalational anaesthesia, and there is still a demand for the sale of the Coxeter valve within which high pressures may be generated easily.

As long as anaesthetists demand such equipment it is not surprising that manufacturers should supply it. There would appear to be room for a greater appreciation, on both sides, of the magnitude of the abnormal pressure changes that may occur using current anaesthetic apparatus and of the possible clinical effects of such changes. The airflow mechanics of anaesthetic apparatus needs more thorough investigation, measurement and definition. It is more likely that there is room for redesign even of some of the simpler equipment.

The flow mechanics of the ideal breathing system for inhalational anaesthesia should be such that there is no more pressure change at the mouth or nose than occurs in normal respiration. It should be self-compensating for its own airflow resistance. Such a machine may not be practicable for everyday use but the ideal might be approached more nearly than is usual at the present time.

The experience gained in the present investigation indicates that any statement of the airflow resistance of an item of anaesthetic equipment should be accompanied by a statement as to precisely how it was measured. Even then care is needed in interpretation. A standard endotracheal catheter mount may be taken as an example. Upon naked eye examination it can be seen that the lumen of the catheter mount used in this investigation is smaller than it need be, and that the internal diameter changes suddenly. The sharp ledge produced by this sudden change in diameter

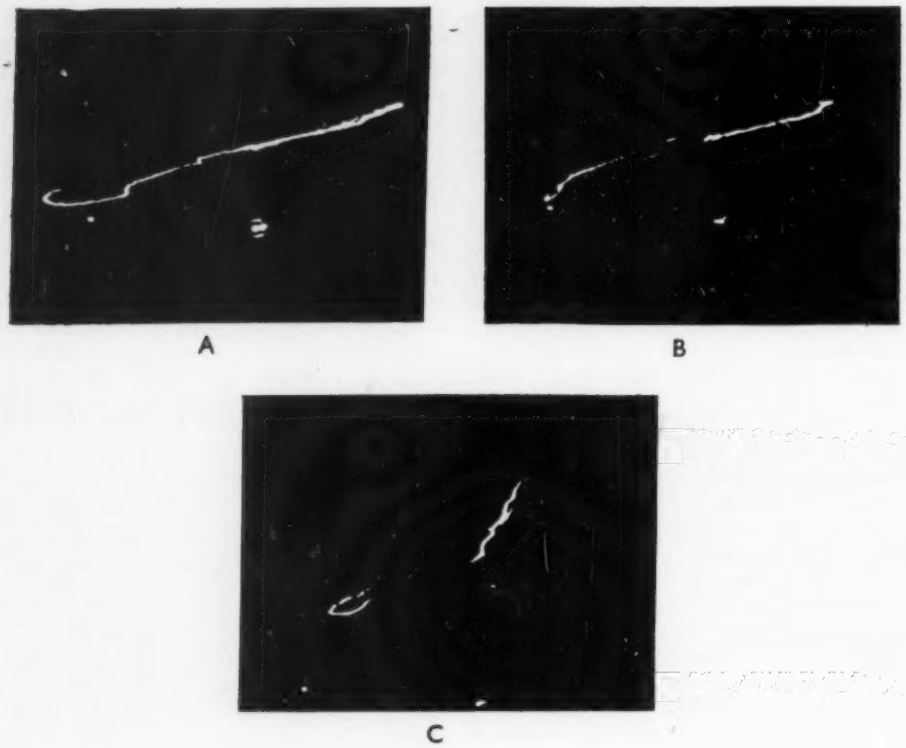


FIG. 17

The flow-pressure loops obtained while breathing into semiclosed anaesthetic breathing systems. Magill system using facepiece. 50 l./min supply.

A. Using reservoir bag. Heidbrink valve, open.
B. Without reservoir bag. Heidbrink valve, open (note peak inspiration).
C. Using reservoir bag with Heidbrink valve. 1½ turns closed.

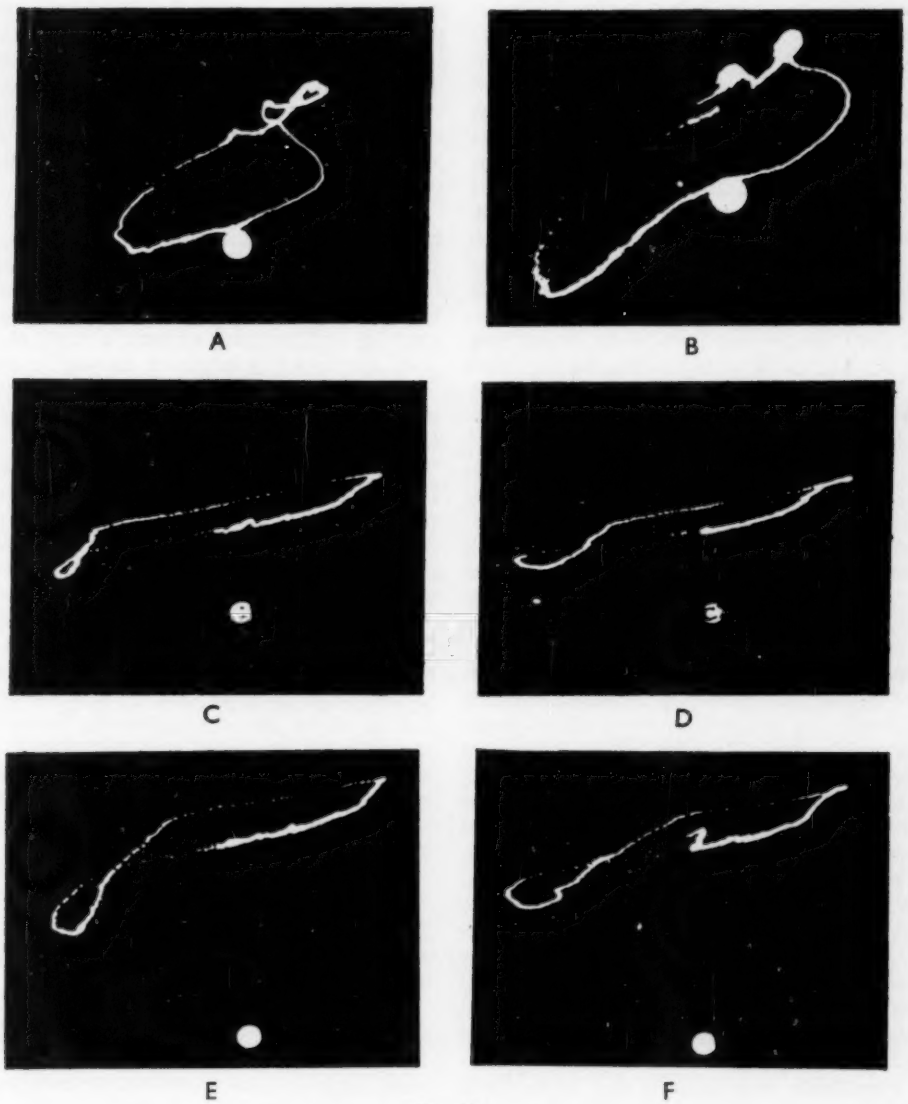


FIG. 18

Flow-pressure loops. A and B: 15 l./min supply, reservoir bag in circuit. Heidbrink valve 1½ turns closed and a No. 10 endotracheal tube connected. A Magill connector was used in A and a Cobb in B.

C to F: 50 l./min supply and using a Coxeter valve and a facepiece. A reservoir bag was used in D and F but not in C and E. The Coxeter valve was used in position 1 in C and D and in position 2 in E and F.

might be expected to disturb airflow through the catheter mount. These points receive confirmation in figure 1. Under the circumstances of that experiment it was found that its airflow resistance was slightly greater than that of the No. 9 Magill endotracheal connector. Furthermore, its airflow resistance could be reduced by "streamlining" the internal ledge with plasticine. But when its airflow resistance was measured in the context of its normal use, as indicated in figures 2, 3 and 4, it was shown to have a "negative" resistance due to a streamlining effect which depended upon the endotracheal connector on to which it was fitted. This does not necessarily invalidate the first conclusions. Had the other items in the system been different and had they offered less resistance, then the resistance of the catheter mount might have been found to be "positive" rather than "negative".

The comparison of the measurements of airflow resistance under steady flow conditions with those made under the dynamic conditions of respiration using peak values suggests that, for all present practical purposes, either may be used for the assessment of the airflow resistance of anaesthetic equipment. When making such measurements, however, the measuring system must be defined. In terms of the initial cost of test equipment it would be cheaper to use basic Rotameter flowmeters and appropriate manometers for steady flow measurements. In terms of the subsequent time spent and the simplicity of actually making measurements it would be quicker and easier, and therefore cheaper, to use a flow and pressure transducer system, such as that described above, in conjunction with a suitable generator of variable airflow. The basic Rotameter and manometer equipment would still be required for calibration purposes. The flow-pressure characteristics of any item or assembly of equipment could be obtained from a single cycle of the variable flow generator, using the X and Y terminals of an oscilloscope or an X–Y recorder.

Throughout this investigation flows were measured at the subject's mouth. When investigating anaesthetic breathing systems, however, invaluable information might be obtained by placing the flow transducer in alternative positions. For example, it would be of interest to measure the flows at the gas supply side of the expiratory valve in the Magill semiclosed system, particularly during expiration. It would be interesting to compare such measurements with the amount of carbon dioxide accumulation in the circuit under the same conditions. It would also be of interest to measure these parameters in the expiratory limb of a circle system while using moderate or high supply flows and keeping the expiratory valve open.

While breathing into an anaesthetic system gas has to be moved against resistance. It has been suggested that the resulting pressure changes may be of clinical importance (Smith, 1961). It would be logical, therefore, to explore the possibility of assessing such breathing systems in terms of the cost, in pressure change, of moving a given volume of gas through the system under respiratory flow conditions. This has not been attempted in this investigation.

In considering the measurements which have been made of the airflow resistance through complete systems incorporating an endotracheal tube, it should be realized that the airflow resistance of that part of the subject's respiratory tract within which the endotracheal tube would lie should be subtracted from the overall resistance values obtained for the complete system. No attempt has been made to measure the airway resistance of the subject of this experiment between the mouth and the upper part of the trachea. The airflow resistance of his nose and nasopharynx, as obtained using peak values, was about 30 per cent greater than that of the endotracheal tube, but the resistance to flow through the left nostril was high.

SUMMARY

Published work on the measurement of the resistance to airflow provided by anaesthetic apparatus is reviewed.

A comparison is made of the airflow-pressure characteristics of certain items of anaesthetic equipment as measured under steady flow and under respiratory flow conditions. An experimental arrangement is described for making such a comparison, in which the equipment is assessed in a context equivalent to that in which it would be used in clinical practice. The use of the Respiratory Analyser for making measurements under conditions of rapidly varying flow is described. It is

concluded that for present practical purposes there is little difference between the characteristics as measured under the two sets of conditions. The importance of defining the precise experimental arrangement when reporting quantitative results with regard to resistance to airflow is stressed.

The airflow resistance of the nose and nasopharynx of the subject used for the respiratory flow experiments was determined in order to put the above measurements into perspective.

Some methods for the assessment of complete anaesthetic breathing systems under respiratory flow conditions are considered. It is suggested that more attention should be paid to the airflow mechanics of anaesthetic equipment and the requirements of an ideal breathing system are outlined.

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EXTRADURAL ANALGESIA AND THE PREVENTION OF POSTOPERATIVE RESPIRATORY COMPLICATIONS

BY

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IN 1902 Campiche, of Lausanne, observed that chest complications are likely to occur after "operations an effect of which is to cause pain on coughing . . . and to upset expectoration and the free functioning of the abdominal pressure". Läwen, in 1912, further remarked: "if we were in a position to produce prolonged anaesthesia, lasting for several days, it is likely that the incidence of bronchitis and pneumonia following laparotomy would be decisively reduced".§ Since this time it has become widely recognized that of all operations those within the abdomen, and particularly the upper abdomen, are most likely to be followed by severe pain and respiratory disturbance (King, 1933; Cutler and Hoerr, 1941; Mimpriss and Etheridge, 1944; Blodgett and Beattie, 1946; Pooler, 1949).

Intra-abdominal surgery involves cutting of the skin and subcutaneous tissues, division or stretching of the muscles of the body wall, opening of the peritoneum, and interference with the viscera. Thus, with the exception of bone involvement, every possible factor in the production of postoperative pain is brought into operation. After surgery the patient must use his anterior abdominal muscles for almost every movement he wishes to make; active participation of these muscles is also required for deep breathing and even more so for coughing. It is not surprising, therefore, that the patient, when left undisturbed, lies still and breathes as quietly as possible. Indeed, the ordeal of taking a deep breath may be such that when the vital capacity is measured it is found to be little more than the resting tidal volume. Reflex muscle spasm occurs and this accentuates the plight of the patient; diaphragmatic movement is restricted and tidal exchange becomes almost entirely dependent upon limited intercostal muscle activity. Underventilation, with retention of secretions, is inevitable and the stage is set for the development of a chest complication.

Although morphine provides some degree of pain relief after abdominal surgery, it by no means prevents respiratory complications: coughing and deep breathing remain distressingly painful. Larger doses of morphine might well improve analgesia but the dangers of drowsiness, respiratory depression and other complications are then accentuated. In either case the patient's well-being depends upon the proficiency and enthusiasm of the physiotherapist and the nursing staff.

In attempting to provide more complete relief of postoperative pain, the disadvantages of central nervous system depression can be avoided by interrupting the pain pathways peripherally. To this end, numerous techniques have been proposed (Simpson and Parkhouse, 1961) but after abdominal surgery many of these fail because visceral pain and resulting reflex muscle spasm remain unrelieved. Extradural blockade of the appropriate segments relieves both somatic and visceral pain, and abolishes reflex muscle spasm, while still leaving the patient alert, co-operative and free from respiratory depression.

Cleland (1949) relieved postoperative pain by means of continuous "peridural" analgesia in 130 cases of abdominal and ano-rectal surgery; he was enthusiastic about the method and reported restoration of "normal" respiration and early,

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§Waren wir in der Lage, eine mehrere Tage anhaltende Daueranästhesie zu erzeugen, so würde wahrscheinlich die Zahl der Bronchitiden und Pneumonien nach Laparotomien stark eingeschränkt werden.

painless ambulation. Blood pressure measurements were not mentioned. Cleland most often used the caudal route, but in a few cases he inserted a needle in the lumbar region and threaded a catheter through this until he estimated that its tip had reached the mid-dorsal level. Subsequently, both Bromage (1954a) and Bryce-Smith (personal communication) have commented on the undesirability of inserting too great a length of catheter into the extradural space; such catheters may curl up, double back, or pass out through an intervertebral foramen (Frumin and Apgar, 1949; Bromage, 1954a). Indeed, one catheter introduced by Bryce-Smith in the course of postmortem studies became tied in a half-hitch knot which would have made withdrawal impossible.

Bonica (1953), after experience with several hundred cases, considered segmental extradural analgesia to be superior to any other method of managing postoperative pain; he used intermittent injections through an indwelling catheter. Bonica stressed the advantages of complete pain relief, effective ventilation and coughing, and willingness to move about.

Massey Dawkins (1956) recommended continuous drip administration of local analgesic solution for the treatment of postoperative pain, through a catheter with its tip lying opposite the third or fourth thoracic vertebra. Commenting on this method, Bonica (1957) pointed out the difficulty of controlling the extent of the block and mentioned an additional danger of continuous administration—progressive, unsuspected fall in blood pressure while the patient is in the sitting position.

The present studies of postoperative extradural analgesia arose from a suggestion of Professor Macintosh that if the patient could be encouraged to stretch his muscles postoperatively, while completely pain-free, reflex spasm might not recur, so that long-lasting benefit would be obtained. Initially, large volumes of local analgesic solutions were injected through an extradural catheter inserted in the lumbar region: with this technique it was possible to encourage deep breathing and coughing but hypotension commonly resulted from the inevitable flooding of the extradural space. Extradural catheters were, therefore, inserted in the mid-thoracic region so that blockade could be limited to the segments supplying the upper abdominal operation site. In this way complete pain relief could be ensured without hypotension and active movement of the patient became possible. In some cases respiratory and circulatory studies were carried out: the results of all these investigations are reported below.

METHOD

Selection of cases.

Studies were made on sixty adult patients admitted to hospital for elective abdominal operations; the age range was from 18 to 77 years, the mean age being 50.9 years. There were thirty-five men and twenty-five women. Physical status varied widely and many patients with pre-existing respiratory disease were included. Table I summarizes the relevant facts about each patient; the numbers allocated to patients in this table are retained in subsequent tables to facilitate cross-reference.

Early in the study, when the lumbar route was used, lower abdominal operations and herniotomies were included in the series. Mid-thoracic extradural block was used only for upper abdominal cases.

Lumbar extradural block.

In these cases the lumbar extradural space was located with a Tuohy needle and a catheter was directed upwards 2 inches (5 cm) beyond the tip of the needle: upper abdominal analgesia thus depended upon flooding of the extradural space with local analgesic solution (Bromage, 1954b). The catheter was inserted when the patient arrived in the anaesthetic room; the operation was carried out under general anaesthesia and the patient was returned to the ward with the catheter in place.

Mid-thoracic extradural block.

The method used for these cases was that recommended by Bryce-Smith (personal communication) as a result of postmortem studies made in 1950. This technique resembles that of Bonica (1956), except that the angle made by the needle with the skin is different (see below).

With the patient either sitting up or lying on his side, and with the spine flexed, a skin weal was made 1 cm lateral to the lower edge of the spinous process marking the upper limit of the chosen interspace: this level varied from the fifth to the eighth thoracic spine. The underlying sub-

cutaneous tissue and muscle were then infiltrated with local analgesic solution and the skin and muscle sheath were punctured with a Sise introducer or wide-bore needle, the skin being held firmly stretched between the fingers of the left hand. The Sise introducer was then withdrawn and a Tuohy needle was inserted through the puncture hole, at right angles to the skin, until the vertebral lamina was reached; the needle was then withdrawn as far as the muscle sheath and re-introduced, aiming inwards at about 10 degrees towards the midline and upwards at about 10 degrees towards the patient's head. When the needle point lay at the depth at which contact had been made with the lamina, the stilette was withdrawn and a 10-ml syringe, filled with saline, was attached to the hub: by slowly advancing the syringe and needle, the extradural space could then be located by "loss of resistance" (Sicard and Forestier, 1921). After a little practice with this method, extradural puncture in the mid-thoracic region proved no more difficult than in the lumbar region.

With the bevel of the Tuohy needle pointing upward, a VX.020 Vinyl catheter (Becton Dickinson), marked at 10-cm intervals, was inserted until its tip lay 4 cm beyond the point of the needle. The needle was then withdrawn and the site of skin puncture sprayed with Nobecutane. The distal end of the catheter was fitted into a chuck designed and constructed in the workshop of the Nuffield Department of Anaesthetics for this purpose (the Oxford chuck, fig. 1), and a test dose of 3 ml of analgesic solution was injected. A rolled 3 × 3 inch (7.5 × 7.5 cm) gauze bandage was placed between the catheter and the skin to avoid a right-angled bend which might cause kinking of the catheter. The catheter was then strapped in position, its distal end being passed over the patient's shoulder with the chuck fixed below the clavicle.

The operation was performed under general anaesthesia, the patient returning to bed with the catheter in place.

Postoperative management.

The authors were informed by the ward sister when postoperative analgesia was required.

The patient's blood pressure was measured, and sufficient local analgesic solution was injected

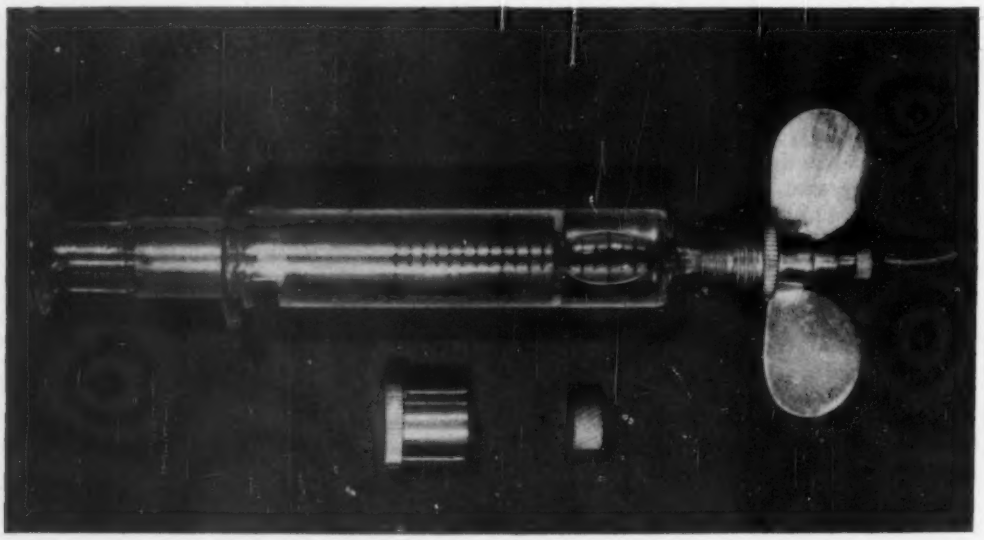

FIG. 1

Syringe attached to Oxford chuck for injection of extradural solution. The inner and outer screw caps may be seen beside the syringe.

through the catheter to provide complete pain relief. Blood pressure was measured again and the patient was encouraged to breathe deeply, cough, and move about the bed. The position of the chuck allowed injections to be given with the patient lying down, and this position was used on all occasions, the head being supported by one pillow. After lumbar injections, patients were instructed to keep their heads low because of the likelihood of hypotension; after injections in the mid-thoracic region patients were kept lying down for 15 minutes to minimize spread of the solution and after this time they could almost invariably sit up or get out of bed without fall in blood pressure. Injections were repeated as often as necessary.

In view of the necessity for scrupulous asepsis, masks were worn by the anaesthetist and the nurse assisting him. The local analgesic solution, syringe, mixing needle and screw caps for the chuck were autoclaved in a small tin which was opened for the anaesthetist, who had meanwhile scrubbed his hands and put on sterile gloves. The nurse freed the chuck from its position below the clavicle, held it by the flanges and unscrewed the outer cap (fig. 1); the anaesthetist then unscrewed the inner cap and laid it aside for re-sterilization. The syringe was attached to the hub of the chuck and the required amount of solution was injected. Finally, fresh inner and outer chuck caps from the autoclaved box were screwed in place.

Respiratory studies.

The patients were visited pre-operatively, and the whole procedure was explained to them. At the time of this visit, vital capacity measurements were made with a dry gas meter: after giving the patient enough practice to achieve his best performance the average of three readings was taken. These measurements were made with the patient lying down so that they would be comparable with postoperative vital capacity readings.

In nine of the patients more detailed studies of respiratory function were made. Before operation, the functional residual capacity was measured using a closed-circuit helium method with the patient in the sitting position and the vital capacity was measured in both supine and sitting positions. The 1-second forced expiratory volume was measured using a spirometer with a light-weight bell and a rapid kymograph. An oesophageal balloon was used to record changes in intrathoracic pressure and a Lilly pneumotachograph to measure air flow. The compliance and nonelastic resistance of the lungs were measured by the method of Mead and Whittenberger (1953), with the modification described by Marshall and Du Bois (1956) for the measurement of compliance. The compliance was measured at the patient's natural breathing frequency but when measured at slower rates it was not appreciably altered, even in patient H.H. (referred to later).

Postoperatively, the vital capacity was measured immediately before pain was relieved by means of an extradural injection; when pain relief was complete a second reading was taken and finally a third reading was taken after the patient had coughed, expanded his chest and moved about the bed. In the nine patients in whom fuller respiratory studies were made, lung compliance and non-elastic resistance were measured before and after the extradural block, and in six of these patients after vigorous movement and coughing. In two patients measurements of compliance and non-elastic resistance were made, in the presence of pain, after the patient had received sufficient intravenous hexamethonium bromide to lower the systemic blood pressure to 75 mm Hg systolic.

In view of the necessity for measuring compliance postoperatively in the supine position, the pre-operative measurements were made in both the supine and sitting positions.

RESULTS

Twenty patients were treated by extensive lumbar extradural block and forty by mid-thoracic block. In twenty-five of these latter cases, all of whom underwent upper abdominal operations, a deliberate attempt was made to keep the patient continuously pain-free for 2 to 3 days after surgery; experience showed that after this time all the patients were able to cough and move without undue discomfort. The remaining fifteen patients received a limited number of extradural injections, designed principally to facilitate physiotherapy (table I).

Analgesia.

Analgesia was regarded as "excellent" if the

TABLE I

Details of patients and type of injection.

(The numbers in the first column are used to refer to the same patients in all subsequent tables.)

Patient	Age in years	Sex	Operation	Respiratory abnormalities	Site of extradural catheter	Nature of analgesia
1	57	M	GE+V	—	Lumbar	Intermittent
2	69	M	RIH	—	"	"
3	40	M	PG	—	"	"
4	59	M	TG	—	"	"
5	53	M	GE+V	—	"	"
6	26	M	RIH	Emphysema	"	"
7	44	F	GE+V	Chronic bronchitis	"	"
8	55	M	BIH	—	"	"
9	61	M	GE+V	—	"	"
10	47	F	GE+V	—	"	"
11	37	F	RFH	—	"	"
12	56	M	GE+V	—	"	"
13	43	F	GE+V+chole	—	"	"
14	49	M	TG	Chronic bronchitis	"	"
15	42	F	Chole	Chronic bronchitis	"	"
16	77	M	Chole	—	"	"
17	42	M	UH	—	"	"
18	18	M	Upper abdominal incisional hernia	Chronic bronchitis	"	"
19	60	M	RIH	—	"	"
20	53	F	Chole	—	"	"
21	60	M	TG	—	Mid-Thoracic	Continuous for 48—72 hours
22	46	F	PG	—	" "	"
23	44	F	Chole	Chronic bronchitis	" "	"
24	60	F	Chole	—	" "	"
25	55	F	Chole+Exp.CBD	—	" "	"
26	62	F	Chole+Exp.CBD	—	" "	"
27	55	M	PG	Chronic bronchitis +emphysema	" "	"
28	60	M	GE+V	Chronic bronchitis +emphysema	" "	"
29	47	M	GE+V	—	" "	"
30	49	M	GE+V	—	" "	"
31	30	F	Chole+exp.CBD	—	" "	"
32	56	M	Splenectomy	Chronic bronchitis +emphysema	" "	"
33	43	F	Chole	—	" "	"
34	75	F	Chole+exp.CBD	—	" "	"
35	40	F	Chole+exp.CBD	—	" "	"
36	57	M	Laparotomy+ liver biopsy	Severe bronchitis	" "	"
37	42	M	PG	—	" "	"
38	35	M	PG	—	" "	"
39	57	M	GE+V	Chronic bronchitis	" "	"
40	46	F	Chole	Chronic bronchitis	" "	"
41	59	M	TG	Chronic bronchitis +emphysema	" "	"
42	69	F	Chole+exp.CBD	Emphysema	" "	"
43	33	M	PG	—	" "	"
44	51	M	Chole	—	" "	"
45	65	M	GE+V	—	" "	"
46	52	F	PG	—	" "	Intermittent
47	45	F	Chole	—	" "	"
48	67	M	GE+V	—	" "	"
49	71	F	GE+V	—	" "	"
50	42	F	Chole	—	" "	"
51	53	F	Exp.CBD	—	" "	"
52	41	M	PG	Chronic bronchitis	" "	"
53	58	M	GE+V	—	" "	"
54	54	F	GE+V	Chronic bronchitis	" "	"
55	61	M	Laparotomy+ liver biopsy	Chronic bronchitis	" "	"
56	39	M	PG	Chronic bronchitis	" "	"
57	50	F	Chole	—	" "	"
58	62	M	GE+V	—	" "	"
59	38	M	PG	—	" "	"
60	36	F	Chole	—	" "	"

Totals: Males 35; females 25. Age range: 18—77; mean: 50·9.

Key GE+V = gastro-enterostomy and vagotomy; RIH = right inguinal hernia; PG = partial gastrectomy; TG = total gastrectomy; BIH = bilateral inguinal hernia; RFH = right femoral hernia; Chole = cholecystectomy; UH = umbilical hernia; exp.CBD = exploration of common bile duct

patient became entirely free from pain and discomfort, even when coughing and moving about; fifty-six cases were included in this category. In one case there was slight residual discomfort on coughing and walking. In the remaining three cases the extradural catheter was extruded (see below): in two of these cases analgesia was excellent for 30 and 48 hours respectively; in the third case it was impossible to provide analgesia after the first three postoperative injections. Thus, taking the series as a whole, analgesia was "excellent" in 93 per cent of patients. Table II gives an analysis of the circumstances in which analgesia was other than "excellent".

The completeness of the pain relief produced by successful extradural block must be seen to be believed. The patient becomes completely unaware of the existence of an upper abdominal wound; his face loses its expression of anxiety and strain, and it is an exciting experience to see a patient, a few hours after gastrectomy, taking deep breaths, coughing vigorously and reaching enthusiastically for his dressing-gown.

TABLE II

Circumstances in which analgesia was classified as other than "excellent".

Patient	Comment
12	Excellent analgesia for three injections. No relief subsequently. Catheter found extruded from extradural space.
23	Excellent analgesia for 48 hours. No relief subsequently. Catheter found extruded from skin.
29	Excellent analgesia for 30 hours. No relief subsequently. Tip of catheter just inside skin.
35	Complained of pulling sensation when walking.

Drugs, dosage and duration of action.

Table III shows the drugs used, the speed of onset of analgesia, the duration of action and the influence of adrenaline. The true duration of drug action was only ascertained in a limited number of cases, since supplementary injections were commonly given before the recurrence of severe pain. In order to exclude the possible influence of hypotension on the duration of drug action, the only cases assessed in table III are those in which the systolic pressure fell by less than 10 mm Hg. There was considerable variation between patients in regard to the dose of local analgesic required to produce complete pain relief (table IV) but in each individual the dose remained remarkably constant. There was no tachyphylaxis from the continued use of lignocaine; other drugs were not used sufficiently often for a definite opinion to be formed.

TABLE IV

Dosage of drugs required to produce upper abdominal analgesia in 40 patients treated by means of mid-thoracic extradural block (patients 21—60).

Quantity of local analgesic solution (ml)	Number of patients
6	2
7	6
8	10
9	12
10	6
11	2
12	1
14	1

Blood pressure.

When the extradural space was flooded with local analgesic solution through a lumbar catheter,

TABLE III

Analgesic drugs used.

Drug	Total number of patients	Total number of injections	Speed of onset of analgesia in minutes	Duration of action in minutes*	
				without adrenaline	with 1 : 200,000 adrenaline
Lignocaine 1·5%	49	981	5—8	80—95	85—105
Amethocaine 0·2%	3	67	10—15	95—115	95—120
Cinchocaine 1 : 600	3	63	12—15	95—120	100—130
Pantocain-plombe	5	33	14—18	—	210—330

*As mentioned in the text, accurate measurements of the duration of action were not made on all the patients referred to in the second column.

TABLE V

Vital capacity measurements (dry gas meter).

Patient	Pre-operative vital capacity (ml)	Postoperative vital capacity					
		In pain (ml)	Percentage of pre-op.	Pain free after extra-dural (ml)	Percentage of pre-op.	*Within 24 hours (ml)	*Percentage of pre-op.
1	1400	500	36	800	57	—	—
2	4200	2900	69	3700	88	—	—
3	3300	1200	36	2100	64	2700	82
4	2200	700	32	1200	55	1500	68
5	1500	700	47	1000	67	1300	87
6	4000	2400	60	3400	85	3700	92
7	1800	700	39	1100	61	1100	61
11	3500	2300	66	2800	80	—	—
12	2900	1300	45	2200	76	—	—
14	3700	1300	35	2400	65	3300	89
16	2300	600	26	1400	61	1500	65
17	2300	1400	61	2100	91	2200	96
18	3400	900	26	3100	91	—	—
19	2700	1000	37	2200	81	—	—
20	2900	1100	38	2300	79	2500	86
22	1200	600	50	600	50	1100	92
23	3400	1700	50	2500	74	2800	82
24	1900	500	26	1100	58	1500	79
25	1600	400	25	900	56	1200	75
27	1700	600	35	1300	77	2000	118
29	3700	900	24	2400	65	2700	73
30	2700	600	22	1800	67	2300	85
31	2400	800	33	1800	75	2000	83
32	1800	800	44	2500	139	2500	139
33	1900	500	26	1200	63	1600	84
35	2000	400	20	1100	55	1500	75
36	1700	600	35	1300	76	1600	94
37	4100	1400	34	2700	66	3500	85
38	2900	1200	41	2200	76	2700	93
39	3300	1000	30	2500	76	3100	94
40	2800	700	25	2100	75	2600	93
41	3500	900	26	1900	54	2600	74
42	1800	1000	56	1300	72	1600	89
43	3800	1500	40	2900	76	3100	82
44	2300	800	35	1800	78	2000	87
45	1700	500	29	1100	65	1200	71
46	2800	600	21	1500	54	1900	68
47	2000	800	40	1400	70	1600	80
48	1500	700	47	1100	73	1100	73
49	2300	900	39	1700	74	1900	83
50	3400	1200	35	2300	68	2600	76
51	2800	600	21	1900	68	2100	75
52	2500	700	28	2300	92	2700	108
53	3100	1200	39	1900	61	2200	71
54	2600	1000	38	2100	81	2100	81
55	3700	1700	46	2500	68	3000	81
56	2200	800	36	1800	82	2000	91
57	3000	1100	37	2000	67	2400	80
58	4200	2000	48	3100	74	3500	83
59	3400	700	21	1500	44	2300	68
60	1900	500	26	1300	68	1400	74

* The significance of these columns is explained in the text.

in order to produce upper abdominal analgesia, hypotension was almost invariable.

With the mid-thoracic approach, the blood pressure fell by more than 20 mm Hg on only two occasions with the patient lying supine. Both of these incidents occurred with the first injection, when the patient's local analgesic requirement was still undetermined. Patients were allowed to sit up 15 minutes after a mid-thoracic injection on a total of 1,025 occasions, and hypotension below 80 mm Hg occurred only fifty-nine times (an incidence of 6 per cent). On all fifty-nine occasions the blood pressure returned to normal when the patient lay down again, and after allowing a little more time to elapse it was possible in every case for the patient to sit and stand without hypotension. In view of the classical belief that small-diameter nerve fibres, such as those of the autonomic nervous system, show the most marked and most prolonged sensitivity to local analgesic agents, it is interesting to note that these patients still had excellent pain relief after their blood pressure had become stable in the standing position.

Respiratory studies.

Table V shows the results of vital capacity measurements made pre- and postoperatively, after the induction of extradural analgesia and again within 24 hours of operation. This last measurement was included in order to facilitate comparison with other publications, since most other workers have quoted postoperative vital capacity measurements made within 24 hours of the operation. In the presence of pain after upper abdominal surgery, in fifty-four cases, vital capacity ranged from 20 to 56 per cent of the pre-operative value, the mean figure being 35.2 per cent. After six lower abdominal operations vital capacity was 37 to 69 per cent of the pre-operative value (mean 55.5 per cent). When pain was abolished by extradural block the vital capacity was 44 to 139 per cent of the pre-operative figure after upper abdominal surgery (mean 69 per cent), and 80 to 91 per cent of the pre-operative figure after lower abdominal surgery (mean 84.8 per cent). These results are given in table VII.

The tests of general lung function which were carried out in nine cases are not reported in full but they showed essentially normal function in all patients except H.H. (patient 28), who showed changes compatible with chronic obstructive emphysema. Tables VI and VIII show the results of the measurements of vital capacity and the mechanical properties of the lungs. In this group of nine cases the vital capacity measured by gas meter in the ward was about 20 per cent less than the volume measured by a spirometer in the laboratory and corrected to B.T.P.S. The gas meter reading was about 12 per cent less than the uncorrected spirometer volume.

Postoperative extradural analgesia had no significant effect on lung compliance (mean change + 1 per cent). In the six patients in whom compliance was measured after effective coughing, mean lung compliance increased by 45 per cent, but vital capacity increased by only a further 16.3 per cent.

Measurements of nonelastic resistance in postoperative patients are liable to show variations due in part to changes in the resistance of the upper airways but in the subjects investigated there was no indication that this resistance changes as a result of postoperative pain or extradural block.

In two patients measurements of vital capacity and lung compliance were made in the presence of postoperative pain, before and after injecting hexamethonium bromide intravenously in sufficient dosage to reduce the systolic blood pressure to 75 mm Hg (table IX). This hypotension did not produce pain relief, which is of interest since ganglion blocking agents are known to relieve certain types of visceral pain (Davis, Moore and Wynn-Williams, 1953). There was no significant change in either vital capacity or lung compliance, although both of these were subsequently improved by extradural block, movement and coughing.

COMPLICATIONS

Respiratory complications.

Only one significant postoperative respiratory complication occurred among the patients treated by this method. A woman of 30 with no pre-existing respiratory disease developed bilateral basal collapse of the lungs on the fourth day after cholecystectomy. Her extradural catheter had been removed 48 hours previously and at the time the complication developed she was able to cough without pain; the condition responded to physiotherapy.

TABLE VI

Vital capacity and tidal volume measurements in 9 patients studied in detail.

Patient	Vital capacity (ml)										Tidal volume (ml) (Lilly Pneumotachograph)			
	Pre-operative		Postoperative (dry gas meter)									Postoperative		
	Spirometer reading corr. to B.T.P.S.	Dry gas meter	In pain	% of pre-op.	Pain-free after extradural	% of pre-op.	After coughing and mov't	% of pre-op.	Within 24 hrs. of op.	% of pre-op.	Pre-op.	In pain	Pain-free after extradural	After coughing and mov't
8	2820	2500	1000	40	2100	84	2300	92	2400	96	810	430	—	540
9	4380	3700	1400	38	2200	59	—	—	—	—	904	596	617	—
10	3140	2500	1000	40	1700	68	—	—	1900	76	740	510	604	—
13	2360	1800	600	33	1200	67	—	—	1400	78	480	452	409	—
15	2920	2200	700	32	1400	64	1600	73	1900	87	570	270	324	362
21	3300	3300	1700	52	1700	52	2200	67	2500	76	990	593	662	640
26	2860	2300	600	26	1600	70	1900	83	2000	87	650	373	451	677
28*	1690	1300	600	46	900	69	1100	85	1100	85	740	410	280	380
34	1990	1700	800	47	1200	71	1600	94	1600	94	730	420	500	670

* Patient H.H., quoted in text.

TABLE VII

Analysis of vital capacity readings (including data from tables V and VI).

Site of operation	In pain (% of pre-op.)			Pain free after extradural (% of pre-op)			Within 24 hours (% of pre-op)		
	Range %	Mean %	Number of cases	Range %	Mean %	Number of cases	Range %	Mean %	Number of cases
Upper abdominal	20—56	35·2	54	44—139	69·0	54	61—139	83·2	50
Lower abdominal	37—69	55·5	6	80—91	84·8	6	92—96	94·7	3

TABLE VIII

Lung compliance and non-elastic resistance in 9 patients studied in detail.

Patient	Lung compliance (ml/cm H_2O)						Non-elastic resistance (cm H_2O/l./sec, at 0·25 .l/sec)			
	(1)	Postoperative						Postoperative		
	Pre-op	(2) In pain before extradural	(3) Pain-free after extradural	(4) % change from (2)	(5) After coughing and mov't	(6) % change from (3)	Pre-op	In pain before extradural	Pain-free after extradural	After coughing and mov't
8	136	112	—	—	161	—	—	6·64	—	5·12
9	253	214	265	+24	—	—	2·44	1·60	2·33	—
10	107	102	69	—32	—	—	4·78	4·06	4·22	—
13	86	106	90	—15	—	—	6·12	2·01	6·82	—
15	73	93	86	—8	92	+7	2·95	2·82	5·77	5·26
21	142	91	91	—	123	+35	6·24	5·19	3·55	4·33
26	98	67	69	+3	107	+55	6·62	5·82	4·35	3·70
28*	101	51	70	+37	120	+72	7·50	—	5·22	5·18
34	95	95	97	+2	147	+52	3·77	2·82	3·02	3·13

* Patient H.H., quoted in text.

TABLE IX

Effect of hexamethonium bromide in 2 patients.

Hexamethonium bromide was administered postoperatively, the patients being in pain prior to the induction of extradural analgesia. In both cases the systolic blood pressure fell to 75 mm Hg.

Patient	Respiratory rate per min		Tidal volume ml		Vital capacity ml (dry gas meter)		Lung compliance (ml/cm H_2O)		Non-elastic resistance (cm/H_2O/l./sec, at 0·25 l./sec)	
	Before hexamethonium	After hexamethonium	Before hexamethonium	After hexamethonium	Before hexamethonium	After hexamethonium	Before hexamethonium	After hexamethonium	Before hexamethonium	After hexamethonium
26	46	32	373	432	600	600	67	75	5·82	4·05
28*	35	38	410	400	600	700	51	67	1·94	4·84

* Patient H.H., quoted in text.

Hypotension.

There is no doubt that hypotension must be accepted as a complication of lumbar injections, if upper abdominal analgesia is to be achieved. This hypotension, being accentuated by posture, makes it impossible for the patient to sit up and move about the bed; thus, the complete pain relief is deprived of much of its potential value.

Extrusion of catheters.

In one case the first three postoperative injections produced excellent analgesia but the next injection was ineffective. It was then discovered that the catheter had worked its way out of the extradural space, and in fact only about $\frac{1}{2}$ inch (1.25 cm) remained deep to the skin. In two other cases the catheter was similarly extruded after 30 hours and 48 hours respectively. This complication was undoubtedly related to the freedom of movement of the patient: it was subsequently avoided by taking care to ensure that the weight of the chuck was not allowed to drag on the catheter, and by allowing plenty of "slack" in fixing the catheter to the patient's back.

Other complications.

There were no other complications; puncture of the dura was avoided and infection did not occur. With appropriate precautions the risk of infection should not be exaggerated; many thousands of cases have been reported by Bonica et al. (1957) and Lund, Cwik and Quinn (1961) in which single or multiple extradural injections have been given without infection. Hingson, Cull and Benzinger (1961) reported a death from sepsis following continuous caudal block but this apparently occurred in unfavourable circumstances, before the days of chemotherapy.

DISCUSSION

Thoracic segmental extradural block abolishes rather than relieves pain, setting an entirely new standard in postoperative analgesia. The following case may be quoted as an example:

H.H., aged 60, was undergoing medical treatment for an acute exacerbation of chronic bronchitis with emphysema when he developed persistent bleeding from a duodenal ulcer. A thoracic extradural catheter was inserted, and gastro-enterostomy and vagotomy was performed under general anaesthesia. Postoperatively, intermittent injections were given through the extradural catheter to maintain analgesia and the patient made a rapid, trouble-free recovery. A chest radiograph 2 days after operation showed an improvement on the pre-operative film. He was discharged home 11 days after operation.

Eight months later this patient was readmited with peritonitis following perforation of the appendix. On this occasion, after emergency appendicectomy he received conventional postoperative analgesia and developed areas of patchy collapse and consolidation in both lungs. Tracheostomy became necessary the day after surgery; this tracheotomy was closed 27 days later, after a stormy convalescence, and he was discharged home 30 days after operation.

(This patient is No. 28 in the present series.)

Despite its advantages, the method has certain limitations. The technique is exacting and time-consuming, frequent injections being necessary in order to provide continuous analgesia. It is, however, quite feasible to give the patient a limited number of injections during the day, to precede

physiotherapy, so that deep breathing, coughing and movement are painless. In the intervening periods, and at night, the patient may be treated by systemic drugs. Unless the facilities of an intensive therapy unit are available this may be as much as can be hoped for, but even this is of great benefit to patients with pre-existing respiratory disease. Similarly, the method has been used to treat patients after thoracotomy (nine cases) and patients with severe chest injuries (twelve cases) with equally impressive results.

Mid-thoracic extradural puncture, although not difficult, requires some experience, and the close proximity of the spinal cord must always be borne in mind. A further technical difficulty is the possibility of extrusion of the catheter unless care is taken to allow scope for free movement of the patient.

The principal limitation of the technique is the brief action of the analgesic drugs available—in this respect progress has been negligible since Läwen made his observations in 1912. In the present series, the duration of action of the several drugs used (table IV) was found to differ considerably from that quoted by Bonica et al. (1957), Cleland (1949) and Bromage (1954c). It may be that the longer effects reported by these authors were related to the volumes of solution used and, pari passu, the degree of hypotension produced. In the present series, in the absence of hypotension, the duration of drug action was impressively constant; furthermore, adrenaline had surprisingly little effect on the duration of analgesia in normotensive patients. On the other hand, the combination of adrenaline with hypotension can lead to considerably prolonged drug action. Although lignocaine had the shortest action, it was used as the drug of choice because of the rapid onset of its action. Theoretically, the maintenance of continuous, complete analgesia with 1.5 per cent lignocaine would necessitate injections at intervals of not more than 90 minutes for the first 48 to 72 hours after operation, that is a total of up to fifty injections. In practice, the maximum number of injections given in the present series was forty-one.

With all drugs used, except Pantocain-plombe, analgesia wore off very rapidly, in contrast to the gradual waning of the effects of morphine and similar drugs; within 10 minutes of experiencing the first twinges of discomfort the patient was in severe pain, and it is important to remember this fact when opiates are not used in conjunction with extradural block.

In the hope of overcoming the problem of frequent injections, Pantocain-plombe solution was used in five cases. This was the only non-aqueous solution used: it is a preparation marketed by Farbwerke Hoechst, Frankfurt-am-Main, which consists of 1.5 per cent amethocaine in 6 per cent kollidon. This drug has been widely used, in single doses, for extradural analgesia in Germany and elsewhere on the continent of Europe for the last ten years (Buchholz, 1951). It is claimed that the amethocaine is released slowly and evenly from the kollidon base, resulting in prolonged analgesia. In our five cases, excellent analgesia lasted for 3½ to 5½ hours, with the added advantage of a gradual return to normal sensation. However, all five patients complained of burning pain at the site of injection after between five and seven injections, that is, after about 24 hours of continuous analgesia. Subsequent injections of alternative analgesic solutions, or even saline, produced the same unpleasant sensation. Use of the drug was therefore discontinued, although there was no evidence of neurological sequelae.

Part of the purpose of the present study was to demonstrate that extradural anaesthesia alone can produce complete pain relief. For this reason morphine and similar drugs were not given in many cases, only quinalbarbitone sodium, 90-180 mg, being used to encourage sleep at night. Nevertheless, having established that extradural analgesia can produce complete pain relief, it is necessary in clinical practice to appreciate the importance of treating minor discomforts, such as the irritation of intragastric tubes, in the post-operative period (Keats, 1956). When a patient remains continuously alert, as with the unmodified effect of extradural analgesia, time hangs heavily on his hands and petty irritations become more noticeable. Thus, it is probable that if extradural analgesia is used for the management of post-operative pain many patients will benefit from the additional adminstration of sedative drugs.

Respiratory studies.

It has been generally assumed that there is a relationship between severe pain, reduced vital

capacity and respiratory complications, and vital capacity measurements have been used as a yardstick of success in the treatment of postoperative pain. However, although good pain relief was always claimed, most workers reported that the vital capacity never rose to more than 60 per cent of the pre-operative value during the first 24 hours after operation (Starr and Gilman, 1942; McCleery, Zollinger and Lenahan, 1948; Pooler, 1949). Only Bromage (1955), who advocated spirometry as a method of comparing analgesic drugs, reported vital capacities as high as 80 per cent of the pre-operative figure; this was after extradural analgesia.

It is of interest to compare vital capacity measurements with studies of lung compliance: the vital capacity is determined by the mechanical properties of the lungs and chest wall, and also by the voluntary effort of the patient; the lung compliance is an objective measurement, and is not affected by voluntary effort. The compliance of normal lungs is related to lung size (Marshall, 1957) and in a short-term study such as this changes in compliance are most probably due to changes in the amount of ventilated lung and not to changes in the elasticity of the lung substance. Ferris, Mead and Frank (1959) and Bondurant, Mead and Cook (1960) have pointed out that changes in posture and increased vascular congestion can produce false results when lung compliance is measured by oesophageal balloon techniques. In the patients in this study there was no difference in the mean figure for compliance measured in the sitting and supine positions (sitting 0.128 l./cm H_2O; supine 0.121 l./cm H_2O). The possibility of vascular effects is discussed below.

The reduced vital capacity after operation is due partly to diminished effort caused by pain on movement of the chest and diaphragm, and partly to decreased compliance of the lung caused by closing off of parts of the lungs by bronchial plugs. The large increase in the vital capacity after extradural block appears to be due solely to the relief of pain. The increase was not an indication that adequate lung ventilation had been obtained, since it was not accompanied by a change in lung compliance. Relief of pain alone was not sufficient to ensure that the patient would clear his bronchi and ventilate all parts of his lungs adequately. It was only after vigorous movement and coughing that increased compliance was observed, indicating that the aeration had really been improved. Thus, the information provided by measurement of both vital capacity and lung compliance emphasizes the need for vigorous physiotherapy to the chest postoperatively.

Apart from the above considerations, vital capacity may be influenced by such factors as bronchodilatation and the amount of blood in the pulmonary circulation. It has been reported, for example, that intravenous procaine will raise the vital capacity even in the absence of pain (Herxheimer, quoted by Lucas, 1950), and Bromage (1956) noted increase in vital capacity following the induction of hypotension in patients with cardiac and respiratory disease. In using extradural analgesia for postoperative pain relief, Bromage (1955) reported that in five patients the vital capacity exceeded the pre-operative value; again, however, four of these five patients had evidence of pre-existing left-sided cardiac strain and pulmonary congestion.

In the present series, although vital capacity increased considerably after lumbar extradural block, it was necessary to exclude the possibility of this increase being a haemodynamic effect associated with the considerable degree of hypotension which commonly occurred. The fact that there was no significant change in either vital capacity or lung compliance after reducing the systemic blood pressure to 75 mm Hg with hexamethonium, in the presence of postoperative pain, strongly suggested that hypotension alone was not responsible for increase in vital capacity in these cases, but that pain relief was, indeed, the important factor. The absence of any significant effect of this hypotension on lung compliance also suggested that errors in measurement due to vascular changes in the lungs were not occurring (Bondurant, Mead and Cook, 1960). When midthoracic blocks were used, analgesia and improved vital capacity went hand in hand in the absence of hypotension, thus confirming these impressions.

These studies suggest that the relative failure to improve vital capacity reported by previous workers was probably a feature of the incompleteness of pain relief in their cases. However, even with the complete pain relief provided by extradural block the vital capacity remains about 15

per cent below the pre-operative value: this may well denote an effect of the extradural block on the intercostal muscles. An alternative explanation is that even after one or two bouts of coughing some small mucus plugs remain to be cleared from the bronchi; however, in the present investigations improvement in lung compliance after coughing was not accompanied by a proportionate increase in vital capacity—in some cases compliance after coughing was above the pre-operative figure although vital capacity remained reduced.

SUMMARY

Extradural analgesia was used for the control of postoperative pain in sixty patients subjected to abdominal surgery. At first, indwelling catheters were inserted into the lumbar extradural space: this procedure enabled widespread block to be induced but hypotension was almost invariable. Subsequently, analgesia was produced by means of small volumes of solution deposited through catheters inserted in the mid-thoracic region. This block was less extensive, and hypotension was usually insignificant. Early ambulation thus became possible, and since complete freedom from pain was afforded, breathing and coughing became easy and efficient.

Vital capacity measurements during the first 24 hours after surgery showed an average return to 85 per cent of the pre-operative level—a significant improvement on previously reported series. Measurements of lung compliance as well as vital capacity served to illustrate the important fact that complete pain relief is valuable for the improvement of postoperative respiratory function only in so far as it enables deep breathing and vigorous coughing to be carried out. Similar studies indicated that improvement in vital capacity after extradural block was a result of the pain relief rather than a haemodynamic effect associated with hypotension.

The method also proved successful when applied to patients after thoracotomy, and patients with severe chest injuries.

The exacting nature of the technique, the necessity for scrupulous asepsis, and the large numbers of injections required, make continuous postoperative analgesia by means of intermittent mid-thoracic extradural block unsuitable for routine use except where the special facilities of an intensive therapy unit are available. Alternatively, a limited number of injections may be given, prior to physiotherapy, or the method may be reserved for selected patients with pre-existing respiratory disease.

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THE EFFECTS OF EXTRADURAL INJECTION OF DILUTE LOCAL ANALGESICS*

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For the past two years extradural injections of local analgesics in low concentrations have been administered to patients suffering from backache or sciatica with the object of assessing their therapeutic effect. In forty-eight of these patients a careful study was made of the course of analgesia and the cardiovascular effects of these injections and also of the comparative properties of 2-chloroprocaine (Nesacaine) and lignocaine. It is the purpose of this paper to report the data obtained in this study.

METHOD

The procedure was carried out in the anaesthetic room; the patients were not premedicated. Control readings were taken of the pulse rate, blood pressure and temperature of the feet. The blood pressure was measured in the conventional manner using a mercury sphygmomanometer and stethoscope. The skin temperature was taken with an electric thermocouple type skin thermometer (Leigh Laboratories, Brighton, England). The patient was then turned on to his side and extradural puncture performed. A No. 18 needle (either straight, short bevelled, or Tuohy type) was inserted into the extradural space via the fourth or fifth lumbar space (except in those patients who had had an operation on the spine, in whom the second or third lumbar space frequently had to be used). A Macintosh balloon was employed to locate the extradural space. A Polyvinylite catheter was introduced through the extradural needle into the extradural space and the needle was withdrawn.

The patient was then turned on to his back and 50 ml of one of the following solutions was now injected through the catheter:

Lignocaine (per cent) 0.2, 0.3, 0.4, 0.5, or
2-Chloroprocaine (per cent) 0.3, 0.45, 0.6, 0.75.

The various dilutions were prepared with normal saline. These relative concentrations were employed because previous workers (Foldes, Colavincenzo and Birch, 1956; Ansbro, et al., 1959) have shown that 3 per cent 2-chloroprocaine is equipotent with 2 per cent lignocaine.

Each of the concentrations of the two agents was administered to six patients. The 50 ml of solution was injected as rapidly as possible and at the end of the injection a stopwatch was started ("zero" time). Blood pressure, pulse rate, skin temperature of the feet, and symptoms and signs were noted at the following times after "zero": 3 minutes, 8 minutes, 12 minutes, 15 minutes, 20 minutes, and every 10 minutes thereafter until analgesia and hypoaesthesia of the skin had disappeared. The patient was then returned to the ward. Motor block was not assessed. Six (two 2-chloroprocaine and four lignocaine) of the forty-eight patients had previously had a spinal operation for "disc syndrome".

RESULTS

The average age of the twenty-four patients who received extradural lignocaine was 42 years and of those who received 2-chloroprocaine was 45 years. With both agents ten patients were female and fourteen were male. The time taken for injection of the analgesic solution ranged from 2 to 6 minutes and averaged 3.5 minutes.

Symptoms caused by extradural injection.

The injection of 50 ml of fluid, extradurally, caused the following symptoms: paraesthesiae, numbness, pain and/or tightness in one or both feet or legs, or in the middle of the lower back. Frequently the sensation spread with increasing volume of fluid injected.

In addition to these localized symptoms there

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was often lightheadedness, throbbing or headache, commonly frontal in situation, or deafness and commencing loss of consciousness. These symptoms necessitated a slowing down of injection. One patient fainted on introduction of the catheter before any solution was injected; she later responded quite normally to the injection of fluid.

The time of onset of symptoms varied as follows:

29	patients	reported	no	symptoms				
				after	injection	of	10	ml of solution
25	of these	,,	,,	,,	20	,,	,,	,,
11	,,	,,	,,	,,	30	,,	,,	,,
4	,,	,,	,,	,,	40	,,	,,	,,

Two patients had no symptoms at all throughout the injection of the whole 50 ml.

Analgesia.

Skin sensation was tested by pinprick; no attempt was made to achieve fine grading of sensation. If the patient could not distinguish pinprick from finger touch this was recorded as "analgesia"; if the prick of the pin was felt but was not as sharp as on normal skin an entry of "hypoaesthesia" was made.

Three minutes after the 50 ml of solution had been injected little analgesia was present; with both analgesic solutions only an occasional patient showed any segments of analgesia. However, with both agents several hypoaesthetic segments could be detected in practically every patient. With each agent the average number of segments of hypoaesthesia at 3 minutes was 6.

Figures 1 and 2 demonstrate that analgesia and hypoaesthesia were more widespread after 8 minutes. It should be pointed out that there were frequently different levels of anaesthesia on the two sides.

Figures 3 and 4 show the maximum spread of analgesia and hypoaesthesia which developed. There was no obvious relationship between the range of analgesia and the presence or absence of operative interference with the spine. Occasionally the sensory changes were of a somewhat patchy distribution. There were more segments of analgesia with 2-chloroprocaine than with corresponding concentrations of lignocaine.

Duration of action.

There was considerable variation in the duration of analgesic effect in the individual patients receiving each concentration of the two agents. Owing to this variability the mean durations of action were not proportionate to concentration. Irrespective of concentration the time of commencement of contraction of the band of analgesia averaged 48 minutes with lignocaine and 41 minutes with 2-chloroprocaine. Analgesia disappeared in an average of 66 minutes with lignocaine and 53 minutes with 2-chloroprocaine. The time to complete disappearance of hypoaesthesia averaged 100 minutes in the twenty-four patients who received lignocaine and 92 minutes in those who were given 2-chloroprocaine.

Cardiovascular changes.

Table I shows the averages of the maximal changes in pulse rate and in diastolic and systolic blood pressure which occurred in the first 20 minutes after injection as compared with the control readings. Although the pulse and blood pressure usually fell over the first 20 minutes there was considerable variation in the degree of fall with all concentrations of both anaesthetics. With 2-chloroprocaine eleven patients had an initial rise in pulse rate; in three of these patients the pulse remained above the control level. Three patients had no change in pulse rate. One patient showed no change in diastolic blood pressure and two patients showed a fall in diastolic pressure of less than 5 per cent.

Of the patients who received lignocaine, four showed an initial rise in pulse rate while seven showed no change in pulse rate. In six patients there was no change in diastolic blood pressure and five had a fall in diastolic pressure of less than 5 per cent.

With both analgesic agents the cardiovascular changes do not appear to have been related to the concentration of solution employed. Falls in blood pressure appear to have been greater with 2-chloroprocaine than with the corresponding concentrations of lignocaine. The blood pressure generally started to recover after 40 to 50 minutes.

Sympathetic block in the lower limbs.

The incidence of warming of the lower limbs with the various concentrations of the two local analgesic agents can be seen in table I. Not infrequently warming commenced earlier in one foot than in the other and occasionally one foot

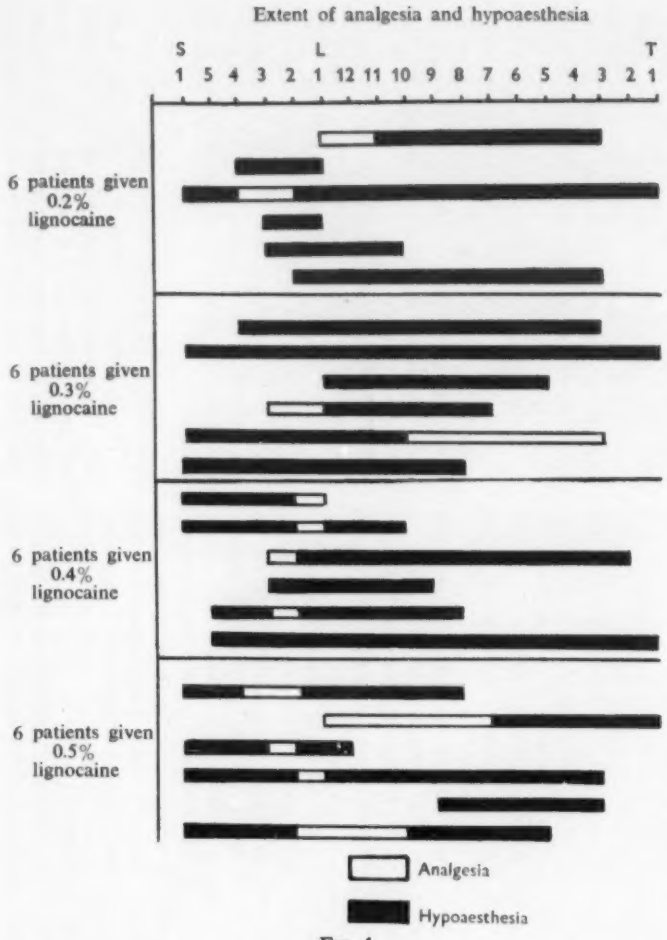
Extent of analgesia and hypoaesthesia
S
L
T
1 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1
6 patients given 0.2% lignocaine
6 patients given 0.3% lignocaine
6 patients given 0.4% lignocaine
6 patients given 0.5% lignocaine
Analgesia
Hypoaesthesia

FIG. 1

Analgesia and hypoaesthesia at 8 minutes after extradural injection.

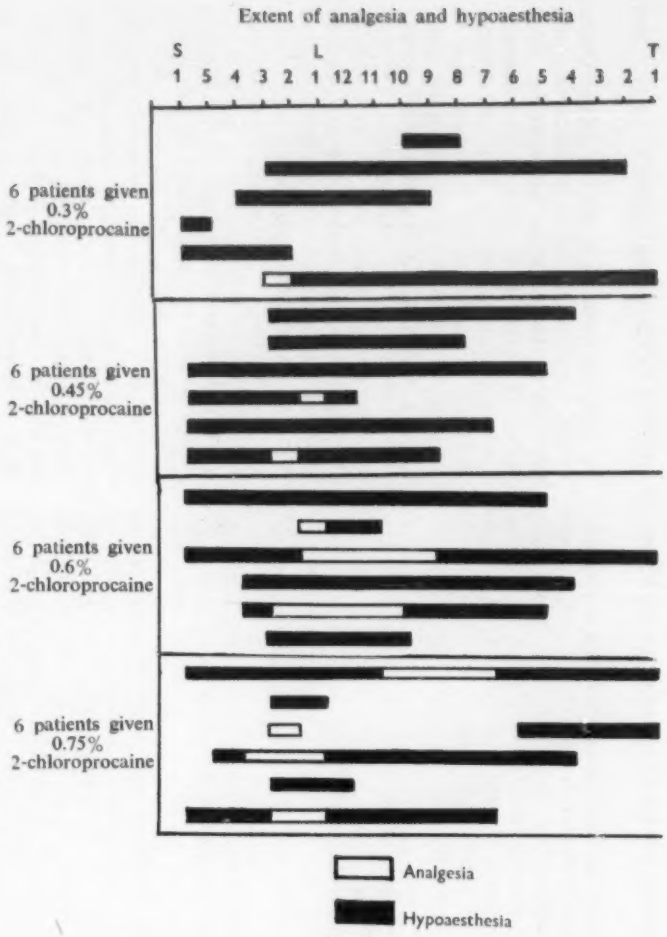
Extent of analgesia and hypoaesthesia
S
L
T
1 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1
6 patients given 0.3% 2-chloroprocaine
6 patients given 0.45% 2-chloroprocaine
6 patients given 0.6% 2-chloroprocaine
6 patients given 0.75% 2-chloroprocaine
Analgesia
Hypoaesthesia

FIG. 2

Analgesia and hypoaesthesia at 8 minutes after extradural injection.

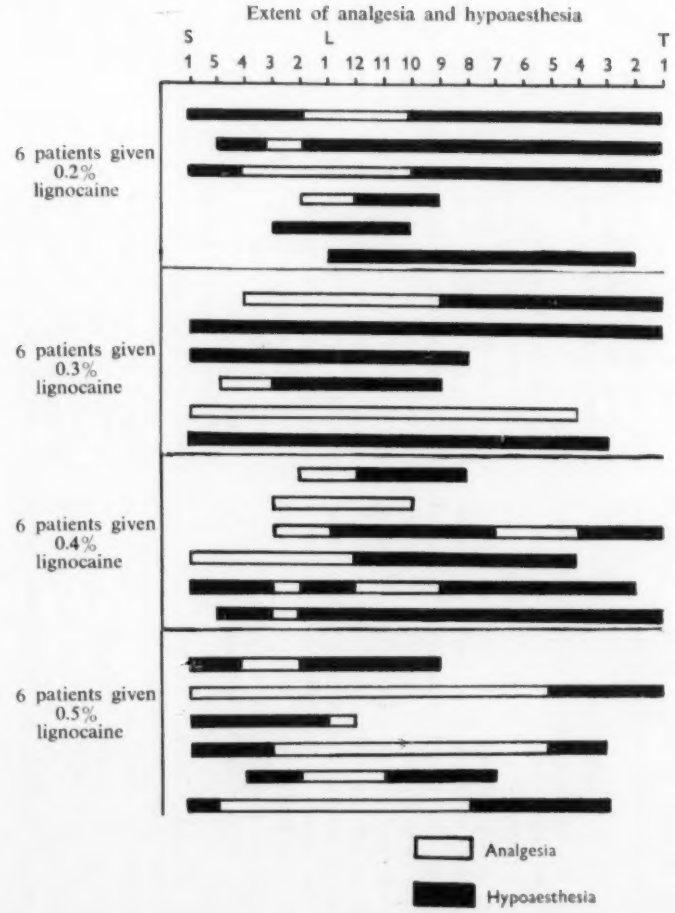
Extent of analgesia and hypoaesthesia
S
L
T
1 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1
6 patients given 0.2% lignocaine
6 patients given 0.3% lignocaine
6 patients given 0.4% lignocaine
6 patients given 0.5% lignocaine
Analgesia
Hypoaesthesia

FIG. 3
Maximum analgesia and hypoaesthesia.

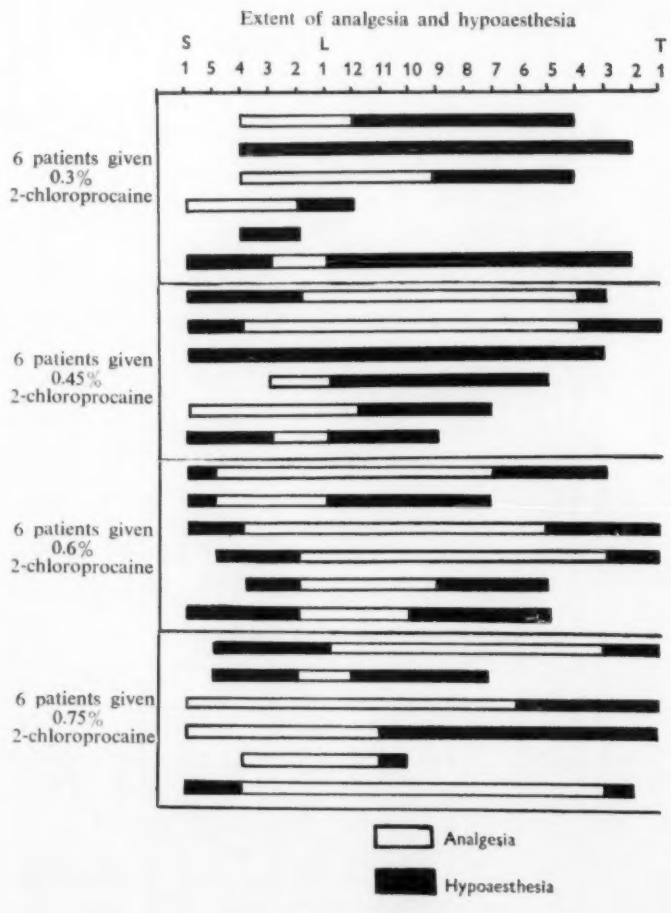
Extent of analgesia and hypoaesthesia
S
L
T
1 5 4 3 2 1 12 11 10 9 8 7 6 5 4 3 2 1
6 patients given 0.3% 2-chloroprocaine
6 patients given 0.45% 2-chloroprocaine
6 patients given 0.6% 2-chloroprocaine
6 patients given 0.75% 2-chloroprocaine
Analgesia
Hypoaesthesia

FIG. 4
Maximum analgesia and hypoaesthesia.

TABLE I

Showing the averages of the maximal changes in pulse rate and blood pressure occurring in the first 20 minutes after injection compared with control readings, and the incidence of warming of the lower limbs.

Averages	0.2 per cent lignocaine	0.3 per cent 2-chloroprocaine	0.3 per cent lignocaine	0.45 per cent 2-chloroprocaine
Per cent fall in systolic blood pressure	21	26	16	26
Per cent fall in diastolic blood pressure	9	14	15	26
Per cent fall in pulse rate	10	8	9	8
Number of patients with warming of lower limbs	1	4	4	6
Averages	**0.4 per cent lignocaine**	**0.6 per cent 2-chloroprocaine**	**0.5 per cent lignocaine**	**0.75 per cent 2-chloroprocaine**
Per cent fall in systolic blood pressure	13	27	23	31
Per cent fall in diastolic blood pressure	12	26	16	22
Per cent fall in pulse rate	10	11	12	11
Number of patients with warming of lower limbs	6	6	6	6

failed to become warm at all. The warming generally outlasted the hypoaesthesia.

DISCUSSION

With the low concentrations of analgesic solutions used in this study there is considerable variation not only in the extent and distribution of analgesia but also in its duration. The fact that all the patients were suffering from backache and/or sciatica and that six of them had had spinal operations means, perhaps, that the data are not strictly relevant to healthy individuals. However, there is no obvious difference in the results in the operated patients and in those with an intact spine. The cause of the variability of effect is related to the factors which influence the spread of extradurally injected local analgesic solutions. These have been stated by Bromage (1954) to be as follows:

(1) Volume of extradural space.
(2) Size of escape routes.
(3) Level of injection.
(4) Volume of solution injected.
(5) Speed of injection.
(6) Gravity.

In the present work the last four of these factors have been kept reasonably constant. The variability of the results found must therefore be accounted for by differences in the volume of the extradural space and in the size of the escape routes.

Bromage has shown that there is a significant relation between age and dosage. The patients in the present study were from a fairly close age group, so that this factor is unlikely to have been of much importance. The patchy analgesia which was sometimes obtained has been explained by Bryce-Smith (1954) as being due to the uneven leakage of solution through the intervertebral foraminae. The great variability of levels of analgesia found in the present patients shows the difficulty of gauging accurately the dose required for any particular height of analgesia.

With regard to duration of action Crawford (1953) found that the duration of analgesia produced by 0.5 per cent lignocaine was 40 minutes and that the duration rose with increasing concentration, 2 per cent lignocaine giving 75 minutes analgesia. Foldes found that when injected extradurally 2 per cent lignocaine gave 40 to 50 minutes analgesia. The duration of analgesia reported in these two studies was found during

the use of extradural analgesia for surgical operations. In the present work the average time of commencing contraction of the band of analgesia in the twenty-four patients who received lignocaine was 48 minutes and in those who were given 2-chloroprocaine it was 41 minutes. This accords with the reports of Foldes, Colavincenzo and Birch (1956), and Ansbro et al (1959), who have found clinically that lignocaine is appreciably longer acting than 2-chloroprocaine.

It appears from the present work that the lowest concentration of lignocaine which will reliably produce sympathetic block in the lower extremities is 0.4 per cent while that of 2-chloroprocaine is 0.45 per cent.

CONCLUSIONS

Extradural administration of 50-ml volumes of low concentrations of lignocaine and 2-chloroprocaine results in very variable and unpredictable levels of analgesia and hypoaesthesia.

Lignocaine provides analgesia of longer duration than that of corresponding concentrations of 2-chloroprocaine.

Peripheral vasodilatation and hypotension were more marked with 2-chloroprocaine than with lignocaine at all concentrations and regardless of the levels of analgesia achieved.

ACKNOWLEDGMENTS

We would like to express our gratitude to Mr. W. Sayle-Creer, M.Ch., F.R.C.S., and to Mr. G. Barlow, F.R.C.S., who referred the patients for epidural therapy. We are also grateful to Sister M. Murphy, S.R.N., and to Mrs. D. Moore, S.R.N., for assistance. Finally, our thanks are due to Miss J. Perry for the diagrams.

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GUANETHIDINE IN HYPOTENSIVE ANAESTHESIA

Clinical Study in Patients Undergoing Microsurgery of the Middle Ear

BY

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When difficult or intricate surgical procedures demand a bloodless operating field, this is usually achieved by hypotension induced with ganglion-blocking agents, combined with posturing of the patient in such a way as to encourage gravitational blood flow from the site of operation. Occasionally, however, such a technique fails to achieve its objective, especially in younger patients who tend to develop a condition commonly termed "tachyphylaxis". This state is characterized by inadequate or fluctuating hypotension, tachycardia and failure of larger or repeated doses of the ganglion-blocking drug to effect improvement. In these circumstances operating conditions are invariably poor. It is doubtful, however, whether "tachyphylaxis" describes accurately the clinical picture observed in these patients. Zaimis (1955, 1956) maintains that repeated doses of ganglion-blocking agents always increase and prolong blockade, and postulates that the apparent resistance is due to these drugs causing a sensitization of the peripheral vascular system to adrenaline and noradrenaline. Nevertheless in such cases we fail to induce effective hypotension or to provide satisfactory operating conditions and "failed hypotension", although not a scientific term, is descriptive of the clinical picture.

Holmes (1961) found that, even in the presence of a satisfactory fall in systolic blood pressure, marked tachycardia was always associated with troublesome bleeding during microsurgery of the middle ear. Figure 1 illustrates such a case. Wound ischaemia was poor, although the systolic pressure was between 60 and 70 mm Hg; tachycardia was of the order of 140 beats per minute and repeated doses of hexamethonium bromide produced no improvement.

Two methods have been advocated to deal with these "resistant" cases. Enderby and Pelmore (1951) suggested that a relatively large initial dose of the ganglion-blocking drug should be given in the fit young patient who could be expected to be "resistant" to ganglionic blockade. Different ganglion-blocking agents have been tried but failure to produce wound ischaemia was encountered with all because tachycardia is a response to ganglionic blockade itself and not to the drug inducing it. Mason and Pelmore (1953) resorted to a myocardium-depressing agent. They administered procaine amide intravenously in doses of 200 to 1,000 mg whenever hexamethonium bromide induced tachycardia exceeding 110 beats per minute. However, neither of these methods has been consistently successful.

More recently halothane has been tried. This drug has the advantage of being more easily controlled and more constant in its effect than procaine amide. In a further attempt to deal with this difficult problem, Holmes (1961) employed hydroxydione and halothane anaesthesia together with hexamethonium bromide and was relatively successful in obtaining hypotension without tachycardia in young patients undergoing microsurgery of the middle ear. However, some patients still proved difficult, even with this potent combination of agents and with high concentrations of halothane.

GUANETHIDINE

Guanethidine (Ismelin), a drug which produces hypotension with bradycardia, was tried in the hope of avoiding the tachycardia which may result from ganglionic blockade. Maxwell et al. (1960) found that guanethidine (2-octahydro-1-azocinyl-ethyl-guanidine) produced hypotension by selective inhibition of the peripheral sympathetic nervous system. The site of action is distal, probably at the adrenergic nerve endings

TABLE I

Fifteen cases of "failed hypotension" with hexamethonium bromide controlled by guanethidine

Patient	Anaesthesia	Dosage of hexamethonium (mg)	Dosage of guanethidine (mg)	Duration of operation (min)	Wound ischaemia
Male aged 25	Thiopentone 400 mg Gallamine 60 mg Nitrous oxide and oxygen with trichloroethylene	50+25	10+10	190	Fair
Male aged 10	Thiopentone 350 mg Gallamine 40 mg Nitrous oxide and oxygen with trichloroethylene	50+25	20+10	365	Good
Male aged 29	Thiopentone 500 mg Suxamethonium 50 mg Nitrous oxide and oxygen with halothane	50+25+25	20+10	330	Good
Male aged 34	Thiopentone 400 mg Suxamethonium 50 mg Nitrous oxide and oxygen with halothane	25+10+15	20	340	Good
Female aged 16	Thiopentone 300 mg Suxamethonium 50 mg Nitrous oxide and oxygen with halothane	50+25	10+10	170	Good
Female aged 22	Hydroxydione 500 mg Nitrous oxide and oxygen with halothane	25	20	255	Good
Male aged 36	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	50	20	175	Good
Male aged 26	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	25+25	20	110	Good
Male aged 15	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	25	20	110	Good
Female aged 13	Hydroxydione 500 mg Nitrous oxide and oxygen with halothane	20+15+10	10+10	120	Good
Female aged 36	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	25+25	20	280	Good
Female aged 22	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	25+25	20	240	Good
Female aged 16	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	20+10	20	100	Good
Female aged 22	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	30+20	20	280	Good
Male aged 23	Hydroxydione 1,000 mg Nitrous oxide and oxygen with halothane	25+25	20	210	Good

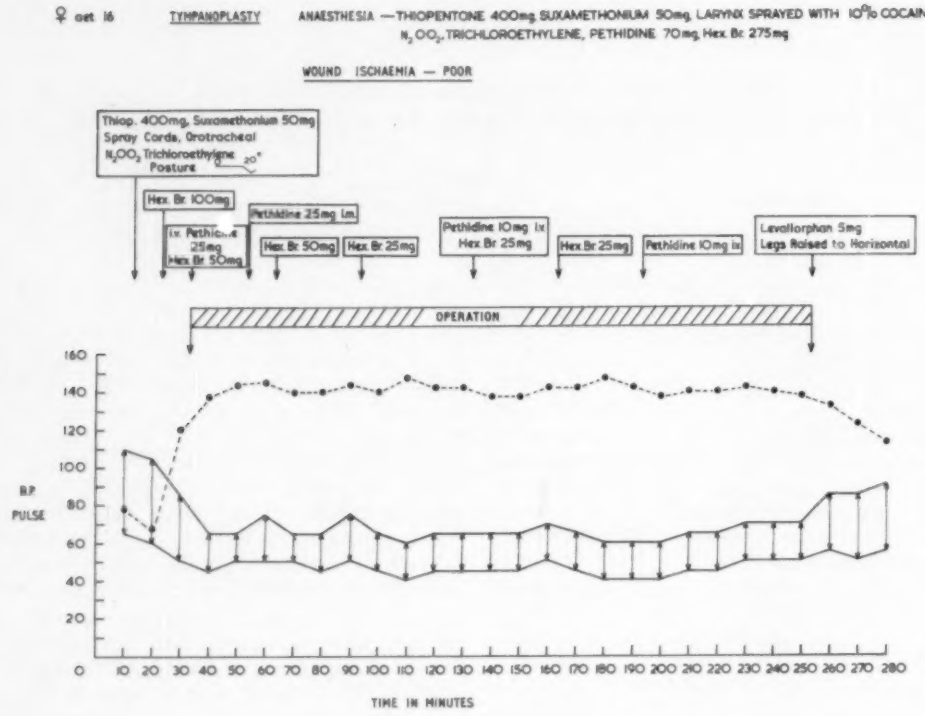

FIG. 1

In spite of adequate hypotension, wound ischaemia was poor in the presence of tachycardia. Repeated injections of hexamethonium bromide and pethidine produced no improvement. (Figure reproduced by courtesy of the editor of *J. Laryng.*)

in the arteriolar walls. Burn (1961) observed that the noradrenaline present in the sympathetic post-ganglionic fibres is reduced in amount when animals are treated with guanethidine, thus diminishing the effect of sympathetic impulses.

Guanethidine appears to interfere with the release or production of noradrenaline, unlike the adrenolytic drugs which antagonize the response to adrenaline and noradrenaline. It intensifies the pressor response to adrenaline and noradrenaline but to some extent antagonizes that to ephedrine, amphetamine, methylamphetamine and phenylmethylamine. Brett et al. (1960) observed that the effects of guanethidine administered intravenously in hypertensive patients may last 48 hours or more.

CLINICAL STUDY

Guanethidine was employed in nineteen patients undergoing microsurgery of the middle ear. In these operations, failure to achieve wound ischaemia is likely to make reconstructive surgery either difficult or impossible. Such procedures are usually lengthy, thus giving adequate opportunity to observe the effects of the agents employed, and the operation per se is not likely to have a material effect on the patient's circulation.

The wound ischaemia achieved in these cases was judged on the surgeon's findings and classified as follows:

Good—middle ear virtually bloodless.

Fair—middle ear sufficiently bloodless to make uninterrupted microsurgery possible.

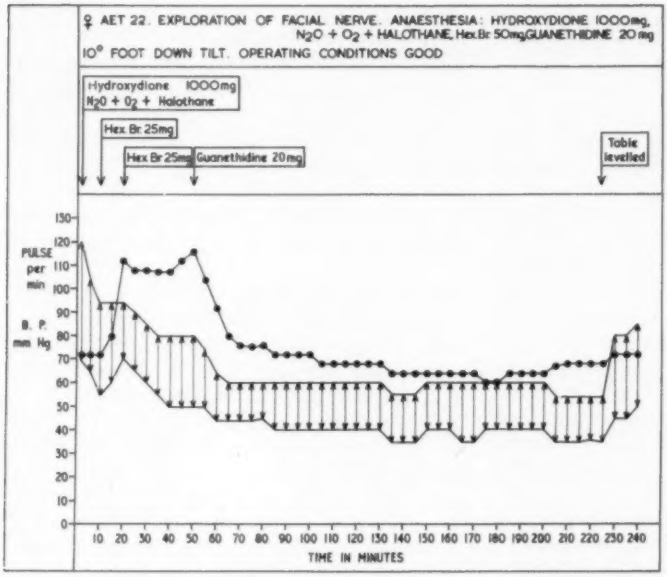
♀ AET 22. EXPLORATION OF FACIAL NERVE. ANAESTHESIA: HYDROXYDIONE 1000mg, N2O + O2 + HALOTHANE, Hex.Br 50mg, GUANETHIDINE 20mg
10° FOOT DOWN TILT. OPERATING CONDITIONS GOOD
Hydroxydione 1000mg N2O + O2 + Halothane
Hex. Br. 25mg
Hex. Br. 25mg
Guanethidine 20mg
Table levelled
PULSE per min
B. P. mm Hg
TIME IN MINUTES

FIG. 2

Marked reduction in pulse rate and moderate fall in blood pressure occurred following injection of guanethidine 20 mg.

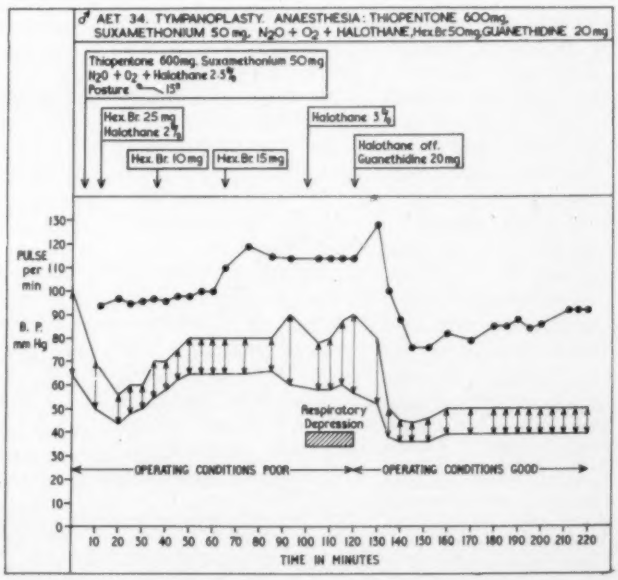

FIG. 3

Illustrates the effect of guanethidine 20 mg in a typical case of "failed hypotension". In spite of repeated injections of hexamethonium bromide and high concentrations of halothane over 2 hours, operating conditions had become progressively worse. The effect of guanethidine was well maintained although the administration of halothane had been discontinued.

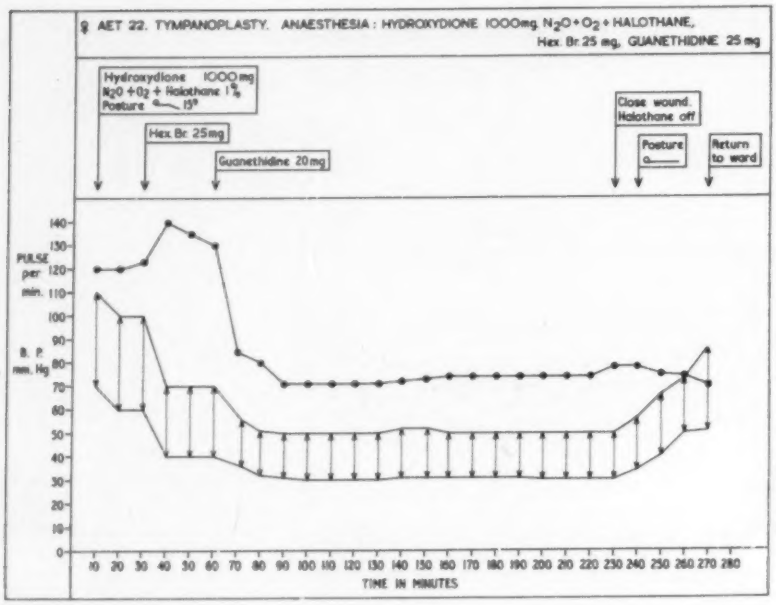
♀ AET 22. TYMPANOPLASTY. ANAESTHESIA : HYDROXYDIONE 1000mg. N2O + O2 + HALOTHANE, Hex. Br 25 mg, GUANETHIDINE 25 mg
Hydroxydione 1000 mg
N2O + O2 + Halothane 1%
Posture 15°
Hex Br 25mg
Guanethidine 20mg
Close wound. Halothane off
Posture
Return to ward
PULSE per min.
B. P. mm. Hg
TIME IN MINUTES

FIG. 4

Showing a typical picture of "resistance" to ganglionic blockade, tachycardia and fluctuating hypotension promptly controlled by guanethidine 20 mg.

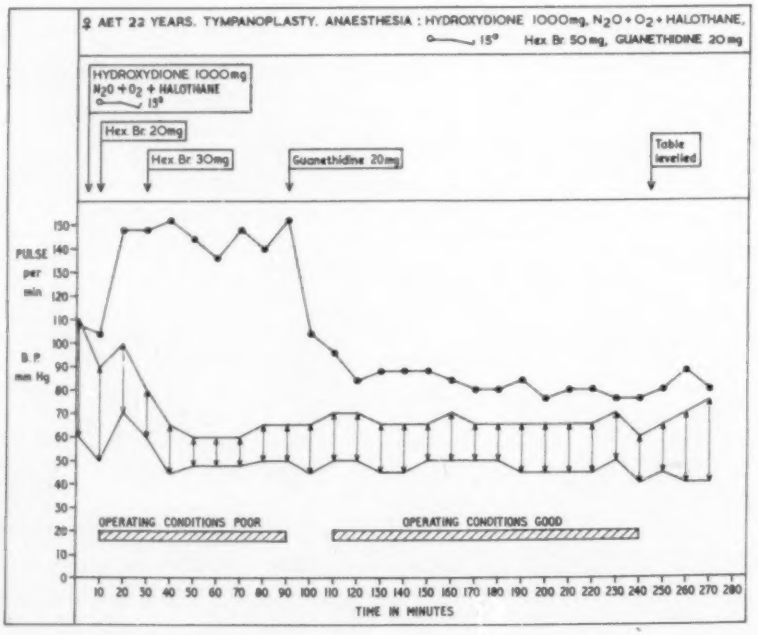
♀ AET 22 YEARS. TYMPANOPLASTY. ANAESTHESIA : HYDROXYDIONE 1000mg, N2O + O2 + HALOTHANE, 15° Hex Br 50 mg, GUANETHIDINE 20 mg
HYDROXYDIONE 1000mg
N2O + O2 + HALOTHANE
15°
Hex Br 20mg
Hex Br 30mg
Guanethidine 20mg
Table levelled
PULSE per min
B.P. mm Hg
OPERATING CONDITIONS POOR
OPERATING CONDITIONS GOOD
TIME IN MINUTES

FIG. 5

Showing that guanethidine can reduce pulse rate without further lowering the blood pressure. The previously poor operating conditions became good as soon as bradycardia developed.

Poor—bleeding sufficient to impede microsurgery, even if only periodically.

The patients were positioned either with the operating table in a head-up tilt of approximately 10 degrees or with the table horizontal in its upper half and tilted 10 to 15 degrees foot-down in its lower half. Both positions encourage pooling of blood away from the site of operation and are likely to intensify the fall in blood pressure to some extent by impairing the venous return to the heart.

The first two patients, fit males aged 33 and 11 years, were anaesthetized with thiopentone, suxamethonium, nitrous oxide, oxygen and trichloroethylene. In each case the administration of guanethidine 10 mg produced a rise in blood pressure and pulse rate within 5 minutes, followed by a gradual fall over the next 10 minutes and resulting in a systolic pressure of 90 to 95 mm Hg, a pulse rate of 70 to 80 beats per minute and poor operating conditions. A further 10-mg dose of guanethidine produced a similar pattern of rise and fall, without improving wound ischaemia. The risk of prolonged hypotension discouraged the use of increased doses of guanethidine (Brett et al., 1960). In an attempt to avoid the initial rise of blood pressure and pulse rate, a 20-mg dose of guanethidine was given intravenously before induction of anaesthesia to the next two patients, who were females aged 33 and 18 years. Both were then anaesthetized with thiopentone, suxamethonium, nitrous oxide, oxygen and sufficient halothane to maintain light anaesthesia. After anaesthesia was induced, the systolic blood pressure was 80 to 85 mm Hg and the pulse rate was 80 to 84 beats per minute. Bleeding was, however, considerable. The subsequent administration of 25 mg of hexamethonium bromide to each of these patients resulted in a systolic blood pressure of the order of 50 to 55 mm Hg and pulse rates of between 70 and 84 beats per minute. Operating conditions now became good and remained so for the rest of the operation which was 2 hours in each case.

The relevant details of the remaining fifteen cases are shown in table I. These were all cases of "failed hypotension", patients in whom hexamethonium bromide, usually administered repeatedly, had failed to produce satisfactory wound ischaemia. For this reason guanethidine had then been resorted to, and was given intravenously in doses of 10 to 20 mg. A reduction in pulse rate occurred in all, usually accompanied by a fall in blood pressure, without initial rise. Wound ischaemia which previously had been poor in all cases, became fair in one and good in the remaining fourteen. Figure 2 illustrates the characteristic fall in pulse rate following the administration of guanethidine, accompanied by some fall in blood pressure. In some of these patients an attempt had been made to improve operating conditions by increasing the concentration of halothane after repeated doses of hexamethonium bromide had failed to do so (fig. 3). However, copious bleeding continued, even after halothane had been administered in sufficient concentration to produce respiratory depression. Thereafter, halothane had been discontinued and a 20-mg dose of guanethidine given, resulting in a fall in blood pressure and pulse rate, and good operating conditions.

In other cases guanethidine was resorted to as soon as the picture of moderate hypotension and marked tachycardia, characteristic of "resistance" to hexamethonium, became evident. Figure 4 illustrates this type of case; in all of these guanethidine controlled tachycardia and produced a bloodless operating field.

The conclusion of Holmes (1961) that tachycardia is accompanied by bleeding even when a satisfactory fall in blood pressure has been obtained by ganglionic blockade is well illustrated by Case 14 (fig. 5). In this patient guanethidine reduced the pulse rate from 140 to 80 beats per minute, while the systolic blood pressure remained unchanged at 65 mm Hg and operating conditions, which had been poor, became good.

Because of reports of prolonged hypotension following intravenous administration of guanethidine (Brett et al., 1960) careful postoperative supervision was maintained. In only one patient was a vasopressor agent required to raise blood pressure at the end of operation; bringing the operating table to the horizontal resulted in a satisfactory level in the remainder. Recovery of consciousness was prompt and postoperative progress uneventful in all patients.

DISCUSSION

In the first four cases in this group, guanethidine alone failed to produce adequate wound ischaemia

for microsurgery of the middle ear. Better results might have been obtained by using larger doses but the risk of prolonged postoperative hypotension discouraged this. Guanethidine provided a bloodless operating field in all cases in whom previous ganglionic blockade had induced only moderate hypotension, tachycardia and poor wound ischaemia. Slowing of pulse rate was always obtained, usually accompanied by a fall in blood pressure. This could be accounted for either by increased peripheral vasodilatation and consequent fall in venous return or by a direct effect on the heart. Cass, Kuntzman and Brodie (1960) observed in rabbits and cats that guanethidine depleted noradrenaline in the heart but not in the adrenal medulla. This finding lends some support to the latter possibility.

The routine use of guanethidine in conjunction with ganglionic blockade is unnecessary but it is suggested that this agent can be useful in patients in whom ganglionic blockade alone has failed to produce adequate operating conditions.

The number of cases presented is small but the effect of guanethidine on the fifteen patients which may be classed as cases of "failed hypotension" were so constant that it was thought of interest to present the results obtained thus far.

SUMMARY

Ganglionic blockade may fail to provide a bloodless operating field in some patients, and in these cases inadequate hypotension is a frequent, and tachycardia a constant, feature.

Guanethidine, a drug which produces hypotension with bradycardia, failed by itself in doses of 20 mg to achieve a degree of hypotension sufficient to provide satisfactory wound ischaemia. In the four patients on whom guanethidine alone was tried operating conditions were poor, although in two of them subsequent injections of hexamethonium bromide resulted in adequate hypotension and a dry operating field.

In fifteen patients who exhibited tachycardia and inadequate or fluctuating hypotension following ganglionic blockade with hexamethonium bromide, the administration of guanethidine resulted in a fall in pulse rate and usually in a further fall in blood pressure.

In these patients, previously poor operating conditions improved strikingly within 5 or 10 minutes following the injection of guanethidine.

ADDENDUM

Since this paper was written, guanethidine has been used in eight further cases of "failed hypotension", with good results in seven.

ACKNOWLEDGMENT

We wish to thank Ciba Limited for generous supplies of guanethidine.

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Brit. J. Anaesth. (1961), **33**, 655

AN ANAESTHETIC TECHNIQUE FOR THE REPAIR OF BRONCHOPLEURAL FISTULA

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THE incidence of large bronchopleural fistula after resection of the lung for carcinoma is fortunately slight as this complication is associated with a high mortality (Gifford and Waddington, 1957). The problems of anaesthesia in such patients and various methods of overcoming them have been described by Parkhouse (1957). Difficulties can arise in these cases as a result of spillover of secretion and leakage of air from the bronchial tree. In a patient with a large fistula respiratory efforts are increased while pulmonary ventilation becomes less efficient. The situation may be further aggravated by spilling of the pleural fluid, which is often infected, into the residue of the lung on the side of operation or even into the contralateral lung. Such a patient becomes rapidly exhausted and it is not uncommon to find spillover fluid rattling up and down in the trachea and bronchi with every breath although there is no effort to cough.

ASSESSMENT OF THE PATIENT

The degree of respiratory distress should be considered in conjunction with the nature and quantity of the sputum, the effectiveness of the cough, the size of the air leak, the degree of anaemia and toxaemia, and the extent to which remaining lung tissue has been damaged by spillover. A recent chest radiograph gives an indication of the amount of fluid remaining in the pleural space but it is important to appreciate that effusions amounting to 500 ml may not be revealed by such a film. The record of respiratory function tests prior to the original operation and the notes on progress afterwards will assist in estimating the respiratory disability before the fistula developed. This information not only allows the anaesthetist to assess the patient's general condition; it also enables him to form an opinion concerning the likelihood of the need for tracheostomy at the end of the operation to allow removal of secretions by suction, if cough was inadequate, or to reduce the deadspace and, if need be, assist respiration by a ventilator.

PRE-OPERATIVE TREATMENT

A patient who is suspected of having developed a bronchopleural fistula should be turned immediately to lie on the affected side in order to avoid contamination of the healthy lung. The contents of the pleural space are then removed as far as is possible, either by aspiration or by insertion of a drain under local anaesthesia. The patient may now be sat up but should be inclined towards the affected side in order to keep the fistulous opening above the level of any fluid remaining in the pleural space. Apparently complete drainage is never a guarantee that the space has been emptied. A chest radiograph is taken after the last aspiration and this should preferably occur immediately before operation for the repair of the fistula.

PRESENT SERIES

The anaesthetic management described here is based on an experience of fifteen patients with bronchopleural fistulae, eight of whom died between 3 days and 4 months after closure of the fistula (table I). Anaesthesia did not contribute to the fatal outcome in any patient. There was one woman aged 36 in the series. The fourteen men varied in age from 50 to 74 years. In five cases the

TABLE I

Serial No.	Sex	Age	Operation	Interval between operation and closure of fistula (days)	Method of selective bronchial intubation	Position on table for closure of fistula	Subsequent course
1	M	66	Right pneumonectomy	22	Carlens	Lateral	Recurrence of fistula and death 2 months later
2	M	51	Right upper and middle lobectomy	6	Carlens	Lateral	Died of bronchopneumonia 9 days after closure
3	M	67	Right pneumonectomy	12	Carlens	Lateral	Developed empyema and died 4 months after closure
4	M	54	Right pneumonectomy	90	Carlens	Lateral	Discharged from hospital
5	M	62	Left pneumonectomy	22	Gordon-Green	Prone	Discharged from hospital
6	M	74	Right pneumonectomy	23	Carlens	Lateral	Discharged from hospital
7	M	46	Left pneumonectomy	21	Gordon-Green	Prone	Improved for a few weeks, but deteriorated and died 2 months after closure
8	M	64	Right pneumonectomy	34	Carlens	Lateral	Died 3 days after closure following recurrence of the fistula
9	M	67	Right pneumonectomy	7	Carlens	Lateral	Recurrence of fistula 7 days after closure and died 4 days later
10	M	63	Right lower and middle lobectomy	8	Carlens	Lateral	Died 4 days after closure
11	F	36	Right pneumonectomy	23	Carlens	Lateral	Discharged from hospital
12	M	56	Left pneumonectomy	19	Gordon-Green	Lateral	Discharged from hospital
13	M	51	Left pneumonectomy	10	Gordon-Green	Prone	Developed empyema and died 10 weeks after closure
14	M	50	Left pneumonectomy	23	Gordon-Green	Lateral	Discharged from hospital
15	M	60	Right pneumonectomy	16	Carlens	Lateral	Discharged from hospital

lesion was in the left lung. The time interval between the original operation and the development of the fistula varied from 6 days to 3 months but in thirteen patients this interval was 23 days or less. All the patients were dealt with by emergency thoracotomy followed by dissection, re-amputation and repair of the bronchial stump. Pneumonectomy had been necessary at the original operation in thirteen of the patients, while a right upper and middle lobectomy and a right middle and lower lobectomy respectively had been adequate in the remaining two cases. It was decided before the second thoracotomy that residual pneumonectomy was necessary in these two cases because the remaining lobe on the side of the operation was already heavily contaminated with spillover. It was not considered necessary, therefore, to protect this remaining lobe, as would have been the case had the surgeon hoped to preserve it.

In all the cases fluid was present in the pleural space; the size of the air leak was also unusually large. For this reason a technique involving bronchial intubation under topical anaesthesia prior to the induction of general anaesthesia was employed in order to prevent the evil effects of spillover and air leak.

ANAESTHETIC TECHNIQUE

Premedication consisted of atropine 0.6 mg only, but if the patient's condition warranted it a small dose of pethidine (25-50 mg) was also given. As the peripheral circulation was often poor these drugs were injected slowly intravenously. Four pints (2 l.) of blood were cross matched for these patients as they were anaemic and the dissection of the bronchial stump in an oedematous infected area could lead to severe haemorrhage. As a first step in the anaesthetic technique the patient was told that it would be wiser not to put him to sleep

at once but that a bronchoscopy and intubation under topical anaesthesia (procedures which were explained to him) would be carried out. The majority of patients accepted this calmly when time was spent in explanation and were co-operative after the procedure had been carefully explained to them. It was sometimes difficult to decide at what stage to tell the patient about these matters. It was left to the anaesthetist's judgment of the patient's temperament whether he was told during the pre-operative visit or on arrival in the anaesthetic room. The anaesthetist who gave the anaesthetic for the previous thoracotomy and who therefore was known to the patient was called upon again whenever possible.

The patient, who had been nursed in the ward sitting up and inclined towards the affected side, was taken to the anaesthetic room in his own bed to avoid the danger of spillover inherent in moving him. As a first stage the drainage tube was unclamped, as coughing during endoscopy might otherwise result either in fluid from the pleural space flooding up through the fistula or in a tension pneumothorax should the fistula be valvular. Adequate topical anaesthesia was obtained by the injection of 2 ml of 4 per cent lignocaine injected through the cricothyroid membrane. The patient was warned that this would cause coughing. The injection was given at the end of expiration to allow the lignocaine to reach the main bronchi before the cough. After 1 minute a further 1 ml of lignocaine was injected to ensure anaesthesia below the site of injection. The patient was informed that the second injection would not cause coughing and when this prophecy was fulfilled his morale was raised, for he felt that all was proceeding according to plan. The back of the tongue, the epiglottis and the larynx were sprayed through the mouth with 4 per cent lignocaine. In edentulous patients the upper gum was also anaesthetized.

As soon as topical anaesthesia had been obtained the patient was given oxygen by a facepiece. This was necessary because these patients are so handicapped that the omission of preliminary oxygenation may lead to a fatality. A bronchoscope was then passed by an anaesthetist standing on a platform above and behind the patient, as this position was by far the easiest for the performance of this operation. Bronchial secretions and spillover fluid were then removed by suction and any abnormality of the carina and bronchial tree noted. Oxygen was administered down the side arm of the bronchoscope. Bronchoscopy was often an ordeal for these conscious patients and it was found that asking them to concentrate on their breathing was the best way of obtaining co-operation.

BRONCHIAL INTUBATION

After further oxygenation with a facepiece, bronchial intubation was performed. A Carlens catheter (Carlens, 1949) was used for the ten cases of a right-sided fistula. This proved satisfactory in every way and gave adequate protection of the left lung. Before the tube was passed, however, the volume of air required to inflate the correctly positioned bronchial cuff, and thus to ensure an airtight fit, was estimated. This was done by inflating the cuff inside a glass tube of the diameter of the average left main bronchus. After the tube had been passed it was assumed to be in the correct position when the hook was felt to engage on the carina. This was confirmed when inflation of the bronchial cuff with the volume of air determined as above produced an airtight fit. If the bronchial cuff was still in the trachea a much larger volume of air was required to make the fit airtight. As a further test the tube leading to the right side of the catheter was occluded, the left side connected to the anaesthetic machine and the patient ventilated with oxygen. Under these circumstances any leak through the fistula was audible or would bubble through the drainage tube, indicating that a communication existed between the two main bronchi. It is impossible to over-emphasize the great care required to ensure that the tube is in the correct position initially and remains so. The importance of this was appreciated when on placing the patient in the lateral position the contents of the pleural space poured up the unclamped right side of the correctly placed tube. The hook, the built-in curves and the inflated cuffs of the Carlens tubes helped to keep them in position and further stability was achieved by the insertion of pharyngeal packs. The hook of the Carlens tube did not inconvenience the surgeon during the repair of the stump of the right main bronchus, it was either tucked down into the left main

bronchus or the whole tube was withdrawn ½ inch (1.25 cm). After the surgeon had evacuated the pleural space and the bronchial stump there was no longer any danger of spillover and the cuffs might safely be deflated for the short period required to re-adjust the position of the tube.

The Gordon-Green (Green and Gordon, 1957) tube was used for the five cases of left-sided fistula. Because this tube has a wider bore than the Carlens it offers less resistance to ventilation and allows the passage of a larger suction catheter for the removal of secretions. However, it is more difficult to position the Gordon-Green tube accurately and to ensure that it stays in place. In consequence, less complete confidence was felt in the protection afforded to the right lung when dealing with a left-sided fistula. If the bronchial anatomy was normal this tube was introduced blindly into the right main bronchus but as its more flexible hook engaged on the carina it did not impart so characteristic a feel to the fingers as did the Carlens tube. The amount of air necessary to inflate the cuff for occlusion of the right main bronchus as opposed to the trachea was also more difficult to estimate. Artificial ventilation and checking for gas leaks proved to be the best tests for accurate positioning. In 2 cases a modified Gordon-Green tube was used. This was passed on a Magill 8 mm bronchoscope (Magill, 1936; Mansfield, 1957; Pallister, 1959). When the tube had been seen to be correctly placed the bronchoscope was withdrawn, leaving the tube in position. Even with this aid, however, it was possible, if the anatomy of the right upper lobe bronchus was abnormal that this structure might be occluded by the cuff and only the right middle and lower lobes ventilated. Auscultation of the chest was therefore necessary to ensure that the right upper lobe was being aerated. As the Gordon-Green tube did not possess the built-in curves of the Carlens catheter the correct position was more difficult to maintain once it had been achieved but again the insertion of a pharyngeal pack firmly round it added to its stability. Constant vigilance was required, however, to ensure that the patient was not moved unless the anaesthetist was actively holding the tube in position. This hazard was exemplified by Case 5 of the series:

A 62-year-old man had developed a bronchopleural fistula 22 days after left pneumonectomy. A Gordon-Green tube was inserted using the technique described. General anaesthesia was induced and the patient was placed on the table in the lateral position. While the anaesthetist was setting up an intravenous infusion, the position of the patient was slightly altered by the attendants. The tube was displaced and signs of soiling of the right lung became immediately obvious. This spillover was not controlled by a 45° head down tilt and suction through the tube. The patient was turned so that the left side was dependent and further spillover prevented. Although the function of the right lung after suction appeared adequate, no safe position for the patient could be found in which the fistula was accessible to the surgeon. Closure of the fistula was postponed and a second attempt made a few days later. The same technique was employed and a Gordon-Green tube again inserted. The patient had his fistula closed in the prone position without mishap and left hospital a month later.

General anaesthesia. Not until the anaesthetist had assured himself that certain protection was afforded to the contralateral lung was general anaesthesia induced. In some cases it was not possible to do this until the patient was actually in position on the operating table. Anaesthesia was induced with a dose of thiopentone sufficient to abolish the eyelash reflex. This was followed by d-tubocurarine and the patient's ventilation was controlled. A nitrous oxide and oxygen mixture was employed for the maintenance of anaesthesia. An intravenous infusion was set up as soon as the patient was in position on the table. At the end of the operation reversal of the d-tubocurarine was obtained with neostigmine preceded by atropine.

Postoperative bronchoscopy. This was desirable in all cases at the end of the operation in order to remove secretions that might have soiled the sound lung during the surgical procedure. It was performed on the operating table either in the prone or lateral position, or afterwards when the patient had been moved on to his bed and was lying on his back. In all cases ventilation with pure oxygen preceded the bronchoscopy to minimize the possibility of hypoxia during this procedure. A sucker was passed down the endobronchial tube before it was withdrawn. In order to facilitate the insertion of the bronchoscope neostigmine for the reversal of d-tubocurarine was withheld until the bronchoscope had passed the vocal chords. Oxygen was administered down the side arm of the bronchoscope so that the patient should be well oxygenated and be breathing adequately and spontaneously when the bronchoscope was withdrawn. Postoperative tracheostomy was necessary in three patients.

DISCUSSION

Although attention to detail is required to ensure success by the method described in this paper, unusual dexterity or experience is not necessary. It may be employed safely by an anaesthetist familiar with the bronchoscopic appearances of the bronchial tree and with the special endobronchial tubes used in thoracic anaesthesia. Adequate time for an unhurried bronchoscopy and intubation is essential. Because the patient is conscious and breathing spontaneously and the fluid level in the pleural space is either below the opening in the bronchus or else the communicating bronchus is inclined upwards out of the fluid at a sufficient angle, the danger of spillover is eliminated. Bronchial intubation followed by thorough testing will ensure that the remaining lung is protected. It is felt that the disadvantages of performing these manipulations on a conscious patient are outweighed by the safety of the method. Experience has shown that these ill and often frightened patients will co-operate if time is spent on explanation and reassurance.

Many thoracic surgeons prefer to operate on patients with bronchopleural fistulae face down (Parry Brown, 1948). The authors, however, prefer the lateral position for the elderly, ill patient with little respiratory reserve, especially if the operation is likely to be prolonged. Extra turning and posturing required to place the patient in the prone position may upset one who is ill, while endobronchial tubes are more likely to become kinked or displaced. However, if there is any doubt in the anaesthetist's mind about the accuracy of his bronchial intubation then the prone position is safer, as the risks of spillover are greatly reduced. Should such doubts arise it is a simple matter to roll the patient into the prone position with the affected side passing underneath. He is then fixed on the table so that the normal side of his chest remains slightly higher than the affected side. In the event of displacement of the bronchial tube free drainage of pleural fluid from the fistulous opening to the trachea occurs without soiling the sound lung. It can readily be removed thence by passing a suction catheter.

SUMMARY

A method of anaesthesia is described for the operative closure of bronchopleural fistula following resection of the lung for carcinoma. The method relies on gaining the co-operation of the patient by explanation and reassurance. After preoxygenation of the conscious patient bronchoscopy is carried out under topical anaesthesia in the sitting position. This is followed by bronchial intubation with careful subsequent testing to ensure that the tube is correctly placed. Under these conditions bronchoscopy and intubation can be performed methodically and without haste, as the anaesthetist is not harrassed by the hazards of spillover and air leak. Only when the anaesthetist is satisfied that the unaffected lung is protected may the position of the patient be altered or general anaesthesia induced. Thiopentone is used for induction and anaesthesia is maintained with nitrous oxide and oxygen, while d-tubocurarine is employed to permit control of ventilation. At the end of the operation bronchoscopy is performed after preliminary oxygenation of the patient. This method has been used with safety in fourteen patients but spillover occurred in the remaining case due to displacement of the endobronchial tube when the patient was moved without the anaesthetist's permission.

ACKNOWLEDGMENTS

The authors are grateful to Mr. T. Holmes Sellors, Mr. Donald Barlow, and Mr. J. R. Belcher for permission to cite cases under their care. Thanks are also due to Mr. H. C. Nohl and Mr. M. F. Sturridge, who performed most of the operations for closure of the fistulae. Finally, we would like to thank Dr. O. P. Dinnick and Dr. W. K. Pallister for their help and advice.

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PERPHENAZINE PREMEDICATION FOR BRONCHOSPIROMETRY

BY

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IT is frequently necessary to undertake investigations entailing some discomfort but requiring the co-operation of a conscious patient. In such circumstances satisfactory premedication is an important factor.

Bronchospirometry is one such investigation. We present here our reasons for finding perphenazine satisfactory as a premedication for patients undergoing this; our findings may suggest its use before other procedures with similar preliminary requirements.

For bronchospirometry we require of the premedication that the patient shall be sedated but co-operative, able to sit up without hypotension, and that his normal respiration shall be disturbed as little as possible. The reasons for these requirements are implicit in the method used.

It is possible to use the traditional morphine and atropine. One of us (S.S.C.) has had experience of its use previously and found it suitable as a sedative: the respiratory depressant action of morphine is, however, a contra-indication, particularly as many of the patients concerned have severely impaired respiratory function. Tranquillizers have therefore been used for our cases.

MATERIAL AND METHODS

One hundred and twenty successful or attempted bronchospirometries are recorded. They were carried out consecutively at this hospital in 1959-60.

The procedure involves the following steps. The operator sits facing the patient, who holds his own tongue forward. The throat and larynx are anaesthetized by spraying with 4 per cent lignocaine and a nasal catheter is passed between the vocal cords for the injection of lignocaine into the trachea. A Carlens tube then has to be passed. For success the patient must breathe smoothly and refrain from gagging. When the tube is in position the patient has to breathe through it into a spirometer for a period of about 5 to 10 minutes.

Premedication was given half to one hour before the procedure; the blood pressure was recorded in the sitting position before it was given, and again before commencing bronchospirometry.

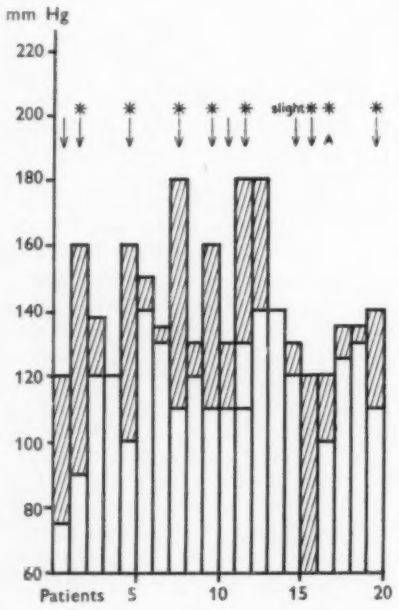

FIG. 1

Chlorpromazine.

Systolic blood pressure before and after premedication with chlorpromazine. Shaded area represents fall of blood pressure.

↓ Fainting.

* Procedure abandoned.

A Apprehensive.

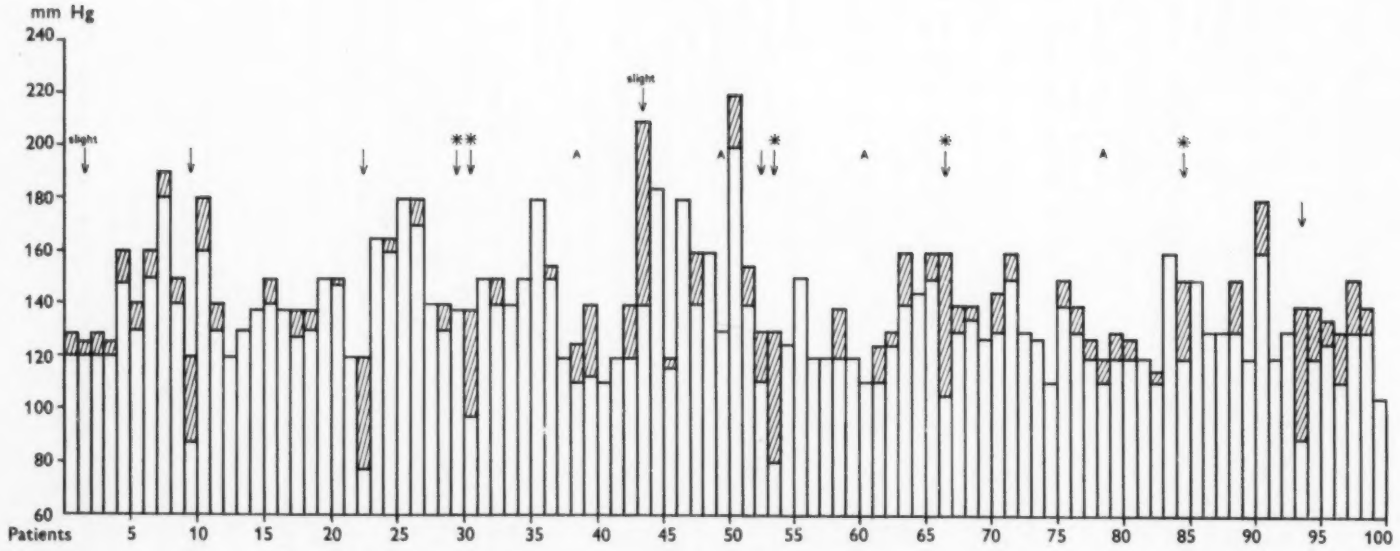

FIG. 7

Perphenazine.

Systolic blood pressure before and after premedication with perphenazine. Shaded area represents fall of blood pressure.

↓ Fainting.

* Procedure abandoned.

A Apprehensive.

In the first series of twenty cases chlorpromazine was used for premedication in a dose of 25 mg intramuscularly. Chlorpromazine was then abandoned on account of many failures associated with hypotension and for the next hundred cases perphenazine was given intramuscularly, in a dose of 10 mg.

RESULTS

The chlorpromazine series.

The results are shown in figure 1. Of twenty consecutive cases, all except two were adequately tranquillized and of the two, only one was seriously apprehensive.

In all except two (90 per cent) there was some fall in systolic blood pressure. This was negligible in two cases (less than 6 mm Hg), slight in three cases (6-10 mm Hg), considerable in thirteen cases (more than 10 mm Hg).

Of the thirteen cases with a considerable fall of blood pressure, eight were too faint for the procedure to be continued. It was completed in the other five but two of them had to lie down throughout.

The remaining seven cases, with little or no fall in blood pressure proceeded without difficulty.

Thus out of the twenty, there were twelve successes and eight failures.

The perphenazine series.

The results are shown in figure 2. Of one hundred consecutive cases, all except three were adequately tranquillized.

In fifty-nine (59 per cent) there was some fall in systolic blood pressure (fig. 2). This was negligible in eight cases, slight in twenty-six cases, considerable in twenty-five cases.

Of the twenty-five cases with a considerable fall in blood pressure, five had to be abandoned on account of severe faintness. In the remaining twenty, bronchospirometry was completed in the sitting position, and only four complained of any faintness or dizziness.

One patient, without any fall of blood pressure, was too apprehensive and subjectively faint for the procedure to be continued.

In the remaining seventy-four patients, with little or no fall of blood pressure, bronchospirometry was accomplished without difficulty.

DISCUSSION

From these two series it is possible to say that both chlorpromazine and perphenazine produced satisfactory tranqillization for this procedure, that hypotension was more frequent and more severe after chlorpromazine than after perphenazine, and that for a given fall in blood pressure there was less subjective complaint with perphenazine than with chlorpromazine. The difference between the two series in respect of considerable fall of blood pressure can be confirmed as highly significant by the χ^2 test.

Applying the same test to the incidence of subjective faintness with a hypotension of more than 10 mm Hg systolic, the difference between the two series falls just short of definite significance, but is at least probably significant. In other words, perphenazine is probably associated with greater subjective tolerance of hypotension than is chlorpromazine.

Perphenazine (Fentazin, Trilafon) has been shown to be less toxic than earlier derivatives of phenothiazine, and effective in smaller dosage (Annesley, 1959; Cahn and Lehmann, 1957; Benson-Harer 1958). The relationship between chlorpromazine, promazine and perphenazine is shown by the structural formulae (fig. 3). They are structurally similar while differing considerably in potency and toxicity.

There are many references to the hypotensive effect of chlorpromazine. It is noted that orthostatic hypotension is liable to occur after intramuscular injection, usually from 30 minutes onwards, that it is often only transitory and rarely causes circulatory collapse (Goldman, 1956; Cohen, 1958; Lear, 1958; Pollack, 1958). There seems to be no direct reference to the degree of hypotension caused by a single small dose such as was given to our first series of twenty patients.

Whilst we confirm that hypotension is a side-effect of chlorpromazine, we have also found it to occur to a lesser degree after perphenazine; other authors have not. In a series of pre-operative administrations (Dobkin, 1959), sedation in labour (Gready et al., 1959), and acute psychoses (Kofman, 1958), where large numbers of patients were given doses of 5 to 25 mg intramuscularly, there was either no significant effect on blood pressure, or an occasional slight fall only reported.

In most of these instances, the figure accepted

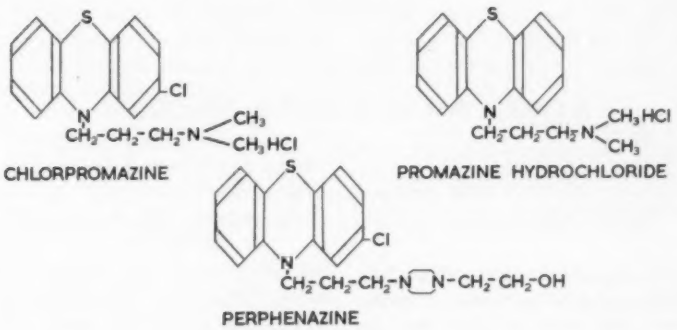

FIG. 3

Structural formulae of chlorpromazine, perphenazine, and promazine hydrachloride.

as a slight fall was not stated, and here it may be that our criteria differ. A fall in systolic pressure of 10 to 20 mm Hg, perhaps insignificant in other circumstances, may cause faintness sufficient to preclude bronchospirometry.

We have found a 25 per cent incidence of considerable hypotension after perphenazine, as compared with 65 per cent after chlorpromazine, whether directly due to it, or despite it (we have not distinguished the hypotensive effect of the drug from the possible hypotensive effect of apprehension); but we have shown that in the perphenazine series the patients seemed to tolerate their hypotension better than with chlorpromazine.

SUMMARY

The efficacy of perphenazine as a premedication before bronchospirometry has been assessed. Compared with chlorpromazine it was equally effective as a tranquillizer and had the advantage of being much less frequently associated with orthostatic hypotension, which can make this procedure impossible.

ACKNOWLEDGMENTS

We wish to acknowledge the advice and help of Dr. T. M. Wilson, Medical Superintendent of Baguley Hospital, the consultants whose patients were part of this trial, and Miss Phyllis Whitehorne. Messrs. Allen & Hanburys Ltd. kindly supplied the Fentazin.

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A CHUCK FOR EXTRADURAL INJECTIONS

BY

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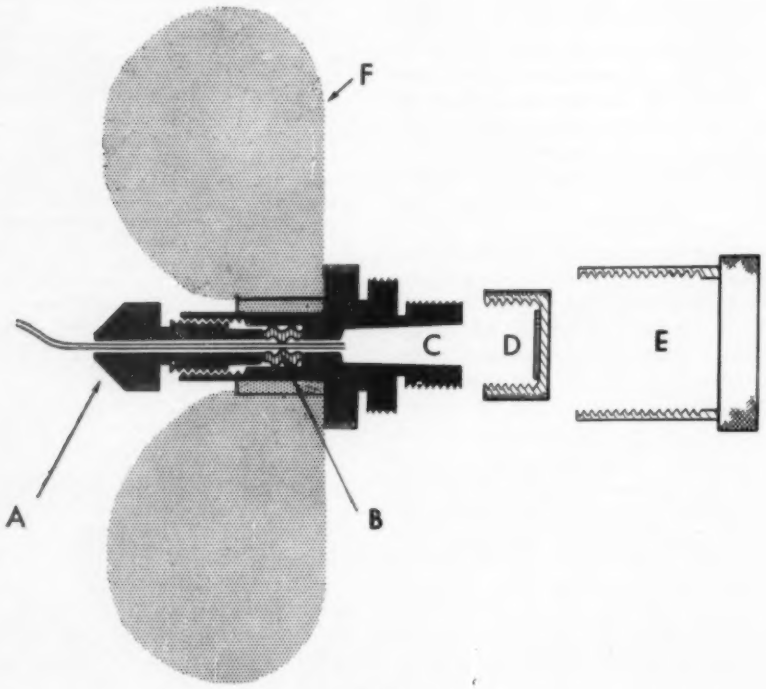
A CHUCK is a means of connecting a catheter to a syringe to facilitate repeated injections (Henderson, 1950). Great care must be taken that the catheter and internal mechanism of the chuck do not become contaminated—particularly when the spinal and extradural spaces are involved—and this chuck has been designed with this object in mind.

The sterile catheter is threaded through the nozzle (with knurled screw) A, and the rubber sleeve B. Rotation of the nozzle now compresses the rubber sleeve, thus attaching the chuck firmly to the catheter as shown in the illustration.

The free end of the chuck has a female Luer taper C to receive the nozzle of the syringe. When the injection is completed, the syringe is detached and the proximal end of the chuck is protected against sepsis by screwing on the sealing cap D. As an additional precaution, cap D is then completely enclosed by an outer cap E, which also screws on to the chuck.

When a further injection has to be given, the



nurse unscrews E, after which the anaesthetist's gloved hand unscrews D—and both of these screw caps are laid aside for resterilization. A small tin is opened which holds a sterile syringe and spare caps D and E.

The body of the chuck is fitted with "wings," F, so that it can be secured comfortably to the patient with strapping. The "wings" also enable a nurse to steady the chuck while the syringe is being attached, and during the injection.

This type of chuck has been in use in this department for some years for repeated injections of local analgesic solutions into the extradural space. Infection has not occurred although catheters have remained in situ, generally for two days and occasionally for as long as a week.

ACKNOWLEDGMENTS

The chuck was made by Mr. L. Bridgman and the drawing is by I. W. Roberts of this department. The chuck is obtainable from Medical and Industrial Equipment, Ltd., 12 New Cavendish Street, London, W.1.

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MODIFIED ANGLE PIECE AND EXPIRATORY VALVE

BY

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A MODIFICATION of a standard angle piece (end-to-side type) for use with the Magill semi-open system and a facepiece has proved satisfactory in anaesthesia for children and adults, and may merit wider use (fig. 1).

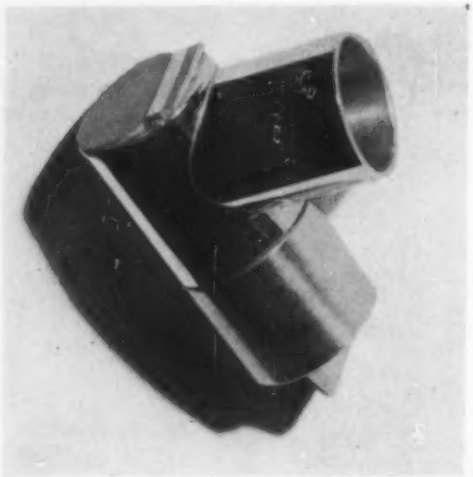

FIG. 1
Modified angle piece and expiratory valve.

In principle, and in purpose, it is very similar to one described by Vale (1959) for children's anaesthesia, designed to obviate the deadspace of the angle piece and to provide a light, latex rubber expiratory valve.

In the modification to be described, greater use is made of the available lumen of the standard conical fittings of the angle piece and the expiratory valve is probably simpler and more robust.

The vertical limb of the angle piece is divided into two equal channels by a partition (A, fig. 2), to provide separate inspiratory (B) and expiratory (C) paths. At the top of the expiratory channel, a hole is cut in the plane surface of the angle piece, which becomes the valve seat. The area of this hole is no smaller than the cross section of the rest of the expiratory channel. The

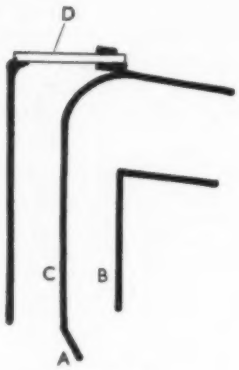

FIG. 2
Sectional drawing of modified angle piece.

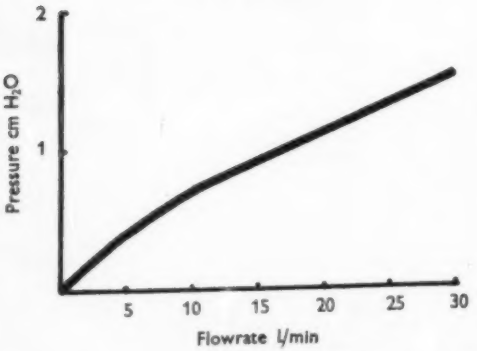

FIG. 3
Pressure-flowrate characteristics of expiratory channel and valve.

expiratory valve (D) is cut from an Esmarch rubber bandage and is held firmly by one edge being forced under a metal strap.

The cross section of each channel is 0.26 sq.in., that is twice the area of a No. 11 endotracheal tube.

Inspiratory resistance is slightly increased by the modification but flow is aided by the Boyle's machine.

The pressure-flowrate characteristics of the expiratory channel and valve are pleasing (fig. 3). The steeper portion of the curve, at low flows, is due to the opening resistance of the valve and is desirable in any expiratory valve to ensure that the reservoir bag of the Magill system fills adequately (Mushin and Mapleson, 1954).

Surgical glove rubber has been tried in place of the thicker Esmarch rubber, but the reservoir bag failed to function.

The reduction in anaesthetic deadspace is 20 to 25 ml, the capacity of an unmodified angle piece, but may be greater if the flange, at the lower end of the partition, separates inspiratory and expiratory streams in the facepiece.

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Brit. J. Anaesth. (1961), **33**, 668

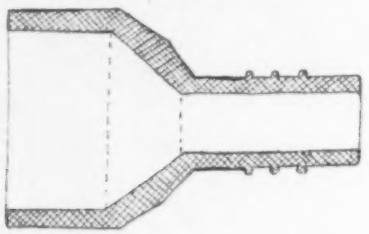
A PLASTIC CATHETER MOUNT

BY

P. H. BEVES

National Hospitals for Nervous Diseases, London

Among the disadvantages of catheter mounts in common use is that, as generally manufactured, they have sharp interior angles militating against laminar flow. The diagram illustrates the longitudinal section of a plastic variant in which the narrowing has been chamfered off. It has been found satisfactory in practice, and seems to be standing up robustly to use. It has the additional advantage of being transparent, so that one can see when it has been properly cleaned.



Longitudinal section (not to scale).

The internal diameter of the narrow end of the model as designed is 10 mm, or slightly more than a size 10 endotracheal tube. The fitting of the wide end is that of the face-mask, viz. female, 0.931″ tapering to 0.9167″ over 0.614″, angle of taper 1° 20′. It is intended to produce two other sizes with bores of 11.5 and 7.5 mm.

The chamfered interior angle is comparable with that of the metal catheter mounts turned for Dr. R. Atwood Beaver at the National Hospital for Nervous Diseases and its design may be regarded as a case of convergent evolution.

This catheter mount was designed to go with a modified version of the Etheridge non-rebreathing valve, a note on which is in preparation.

Those who have not the facilities for turning their own plastic may like to know that R. Ransley, 21 Chiswick Road, London, W.4., can supply copies at about 10*s.* each.

REFERENCE

Etheridge, F. G. (1958). Automatic non-rebreathing valve. *Brit. J. Anaesth.*, **30**, 245.

CORRESPONDENCE

AWARENESS DURING SURGERY

Sir,—I was interested in Dr. Hutchinson's article on "Awareness during Surgery" in the September issue (*Brit. J. Anaesth.*, **33**, 463) as I had a similar experience myself.

After being torpedoed in the Mediterranean in January 1942, I was put ashore at Tobruk suffering from oil burns. During anaesthesia for the cleaning and dressing of the burns, in addition to being aware that my nails were being pulled upon, I also remember quite clearly waking up and experiencing a sensation as though all my fingers were suspended at the tips by threads which all led to a common point. I was idly swinging my wrists on these threads when I heard a voice say, "Look at this". All conversation stopped and a girl laughed. A few seconds later I was unconscious again.

While awake I realized I was still in the theatre, but assumed the operation was finished and was in no way apprehensive. I had no pain or discomfort. I could not see, as I was blind from the effects of the oil at this time. I presume I was having burn dressings done under thiopentone only (my face was also burned) and, when the anaesthetist's attention was called to my activities, he injected a few more ml of thiopentone. His caution in giving the thiopentone in such small increments is to be commended as, two days later, after a journey to Alexandria, I looked so ill that two R.A.M.C. orderlies tried to transport me to the mortuary!

If the anaesthetist has survived the fall of Tobruk, which occurred shortly after this, and the hazards of the rest of the war, he may recognize and remember this incident from the above description.

All other reported cases of consciousness during the course of anaesthesia have occurred since the introduction of curare and its use in large doses with nitrous oxide and oxygen only, or in combination with minimal doses of narcotics. My case is unique also in that it is reported by the patient, not the anaesthetist!

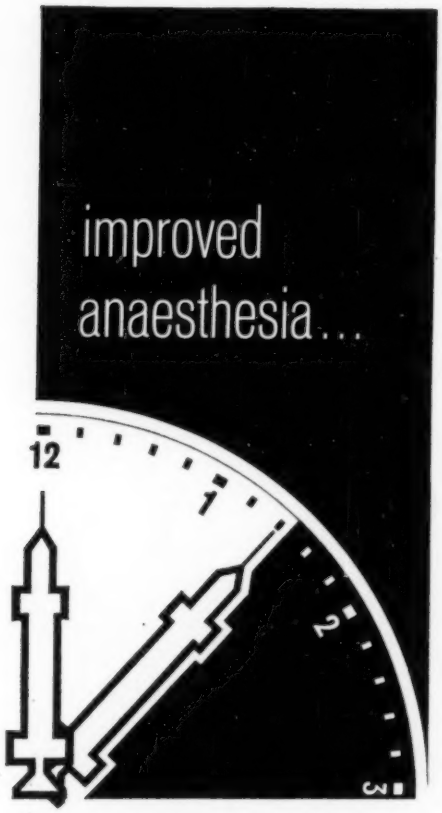
W. M. Brown
Belfast

VACANCIES IN NEW ENGLAND

Sir,—We have available openings for anaesthesia residents at this institution. Appointments are made throughout the year.

Those interested may write directly to me for details.

Benjamin E. Etsten,
Tufts University School of Medicine, Boston 11, *Massachusetts, U.S.A.*



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CONTENTS

PAGE

EDITORIAL 599

ORIGINAL

Vascular distensibility of the hand during pressure breathing 600
By W. E. Watson, D. Phil., M.R.C.P., Department of Neurology and Respiration Unit, Churchill Hospital, Oxford, England.

Changes in vascular distensibility of the hand resulting from alteration of the composition of alveolar air 606
By W. E. Watson, D. Phil., M.R.C.P., Department of Neurology and Respiration Unit, Churchill Hospital, Oxford, England.

The effects of external resistance to respiration. Part II: Resistance to respiration provided by anaesthetic apparatus 610
By W. D. A. Smith, O.B.E., M.B., B.S., F.F.A.R.C.S., Research Department of Anaesthetics, Royal College of Surgeons of England, Lincoln's Inn Fields, London.

CLINICAL

Extradural analgesia and the prevention of postoperative respiratory complications 628
By B. R. Simpson, F.F.A.R.C.S., J. Parkhouse, M.A., M.D., F.F.A.R.C.S., R. Marshall, M.D., and W. Lambrechts, M.B., Ch.B.(Cape Town), D.A., Nuffield Department of Anaesthetics, University of Oxford, England.

The effects of extradural injection of dilute local analgesics 642
By M. Swerdlow, M.D., M.Sc., F.F.A.R.C.S., D.A., and J. Brown, M.B., Ch.B., Salford Hospital Group, Manchester, England.

PAGE

Guanethidine in hypotensive anaesthesia: clinical study in patients undergoing microsurgery of the middle ear 648
By K. B. Holloway, M.B., F.F.A.R.C.S., D.A., F. Holmes, L.R.C.P., F.F.A.R.C.S., D.A., and C. F. Hider, M.B., F.F.A.R.C.S., Department of Anaesthetics, Royal Infirmary, Edinburgh, Scotland.

An anaesthetic technique for the repair of bronchopleural fistula 655
By P. H. Dennison, M.R.C.S., L.R.C.P., F.F.A.R.C.S., D.A., London Chest Hospital, and E. R. Lester, M.B., B.S., F.F.A.R.C.S., D.Obst.R.C.O.G., The Middlesex Hospital and London Chest Hospital.

Perphenazine premedication for bronchospirometry 660
By S. S. Chatterjee, M.B., B.S., M.R.C.P., and S. Jennett, M.B., Ch.B., Department of Respiratory Physiology, Baguley Hospital, Manchester, England.

APPARATUS

A chuck for extradural injections... ... 664
By B. R. Simpson, F.F.A.R.C.S., and R. H. Salt, F.I.B.S.T., Nuffield Department of Anaesthetics, University of Oxford, England.

Modified angle piece and expiratory valve 666
By C. J. F. Potter, M.A., M.B., B.Chir., D.A., The Royal Sussex County Hospital, Brighton 7, England.

A plastic catheter mount 668
By P. H. Beves, National Hospitals for Nervous Diseases, London.

CORRESPONDENCE 669

INDEX 671

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